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Research on PCI Sequence Optimization in Large-scale Mobile Communication Networks based on Genetic Algorithm

Yifan Zhang #, Tianxiang Huang #, Shipu Wei #

School of Electrical and Information Engineering, Anhui University of Technology, Ma'anshan, 243032, China
#These authors contributed equally

Abstract: This study focuses on the importance of physical cell identifier (PCI) planning in large-scale mobile communication networks to reduce inter-cell conflicts, confusion and interference. Genetic algorithms are used to solve the PCI sequence optimization problem in wireless communication systems with the goal of reducing mobile reselection events caused by PCI conflicts, confusions and mode 3 interference. Iterative population selection, crossover and mutation operations are used to search and optimize PCI sequence configurations through a genetic optimization framework. Design PCI reallocation schemes for 2067 cells to minimize the sum of MR data points due to inter-cell conflicts, confusions and interference. Construct conflict matrix A, confusion matrix B, and interference matrix C. Determine inter-cell relationships and intensity metrics based on MR data to ensure that the total number of three MR data points is minimized under the new PCI plan. Conflict MR, confusion MR and mode 3 interference MR are optimized as decision variables, and the objective function is constructed to minimize the sum of interference MR, confusion MR and interference MR by adding them together, and solved by using the genetic optimization algorithm to ensure that the total number of MRs in 2067 cells is minimized. The optimal solution 55989824 is finally obtained through data processing, establishment of connectivity relationship network, integer planning model and genetic algorithm solution. This research result provides a strong support for optimizing network performance and improving user experience.

Keywords: Genetic Algorithm; PCI Sequence Optimization; Cell Phone Network.

1. Introduction

In wireless communication networks, the PCI planning problem is complicated by factors such as channel overlap and signal interference [1]. Dynamic PCI planning aims to reduce conflicts and confusions and improve network performance by adjusting PCI allocations according to network state changes. Considering channel overlap, signal interference, and conflict and confusion in measurement data, the goal of dynamic PCI planning is to optimize the quantity and quality of measurement data while reducing the level of conflict and confusion. We get the relevant data in http://mathorcup.org/. The sum of the number of conflicting MR data points, the number of obfuscated MR data points, and the number of mode 3 interfering MR points among each other is minimized by the PCI reallocation scheme for a particular cell.

To make the PCI allocation with the minimum number of MRs in a cell, we optimize the conflict MR, confusion MR, and mode 3 interference MR as three decision variables, construct an objective function that sums the interference MR, confusion MR, and interference MR, and determine the optimal solution by finding the minimum value of the objective function. First, we process the data, consider each cell as a node, according to the adjacency relationship, adjacency is 1 and non-adjacency is 0. The connectivity relationship between the cells is transformed into a 0-1 matrix, and an undirected unweighted graph is constructed based on the matrix, and then, based on the connectivity relationship between the cells in the network, we compute the cell's reallocation of the PCI (noting that the range of the value of the PCI (note that the range of values of PCI is 0-1007) and then calculate the number of MRs after cell reassignment of PCI. In this problem, according to the conditions of the topic we assign the weight value of the number of conflicting MR, confusing MR, and interfering MR to 1, and find the optimal solution after linearly summing the three MR numbers, and due to the huge amount of data that needs to be solved, we use the genetic optimization algorithm to do the solving.

2. PCI Planning Model for Mobile Communication Networks

2.1. PCI Planning Model Modeling Preparation

2.1.1. Assumptions of the Problem

Although the variables are discrete in the real problem (PCI allocation), the objective function may be assumed to be continuous and differentiable during optimization to facilitate the use of gradient or similar optimization methods. We also assume that there are no other unconsidered factors in the environment that affect inter-cell interference, such as weather variations, building shading, and other non-static factors. During the model solving process, we consider that key factors such as the location of the cell, user distribution, and service requirements remain constant, or at least do not change significantly until the optimization is complete, and that there exists a unique PCI allocation scheme that allows the objective function to reach its minimum value.

2.1.2. Interpretation of Nouns

1.Neighborhood: In the framework of wireless communication system, if a device can capture and receive signals from cell j at the same time under the master connection state of cell i, then we can define cell j as the neighborhood of cell i, referred to as neighborhood.

2.Physical Cell Identity (PCI): PCI is a unique identifier used to differentiate between different cells in a mobile communication network, and is used for downlink synchronization and cell search process.

3.Conflict: In a mobile communication network, PCI conflict may occur when two or more cells are assigned the same PCI. This may cause the UE to be unable to correctly distinguish and select service cells, thus affecting wireless resource allocation and network performance.

4.Confusion: PCI confusion refers to the fact that two or more same-frequency neighbors in the same master cell are assigned the same PCI, resulting in possible mis-switching by the UE during cell switching and causing service interruption.

5.Modulo-3 Interference (Modulo-3 Interference): Modulo-3 interference occurs when the master cell has the same PCI Modulo-3 assigned to its overlapping coverage neighbor on the same frequency. This is because the position of the cell reference signal on the symbol period is fixed, and PCIs with the same modulo-3 will cause the reference signals to be too close to each other in time-frequency resources, which increases the interference and reduces the signal quality.

6.Measurement Report (MR): MR is the data regularly reported by the UE during the communication process.4 It contains information on the master cell currently accessed by the UE as well as information on the received signal strength of the neighboring area, and is an important basis for PCI planning.

7.Integer Linear Programming (ILP): In PCI planning, the optimal PCI allocation for a cell is determined by building an integer linear programming model to minimize the negative impact of factors such as conflicts, confusion, and mode 3 interference.

2.1.3. Data Processing

1. whether to optimize small information extraction:

We extract the data from http://mathorcup.org/ and divide it into three types: cell basic information, conflict and interference matrix data, and confusion matrix data. For type I cell basic information, we filter out whether to optimize the cell, the output is a new matrix, the matrix is the basic information of the cell to be optimized, extract the first column of data that is the number of the cell to be optimized. For type two conflict and interference matrix data, in the Excel table using the VLOOKUP function will be the first column and the second column of data and the need to optimize the number of the cell for comparison, locate and 2067 cell number of different rows to be deleted to get the need to optimize the cell's conflict and interference matrix data. For type III confusion matrix data, use the same method as for type II to get the confusion matrix data of the cells that need to be optimized.

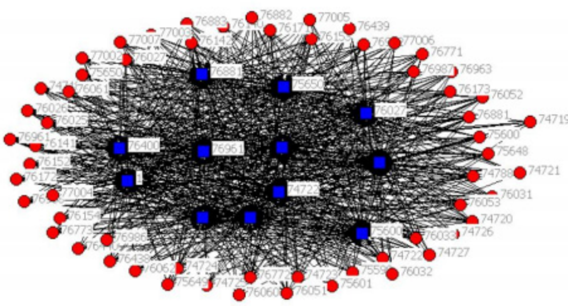

Fig 1. Partial cell network relationship diagram

2.Construction of the 0-1 matrix

In analyzing the impact on neighboring cells, we need to find out the adjacency between the cells. Therefore, we need to filter the data and select the 2067 cells and their adjacent cells, if the two cells are adjacent to each other is set to 1, otherwise it is 0. The adjacency between these cells is transformed into a 0-1 matrix, and the cell adjacency is visualized according to the 0-1 matrix. Some of the cell network relationship diagrams are shown in Fig. 1.

2.2. Modeling of the PCI Planning Model

2.2.1. Model Data Representation

During our study we minimize the sum of the allocated conflicting MRs, confusing MRs, and mode 3 interference MRs by reallocating the PCIs [2], so we first need to carve out the number of relevant MRs.

1) Conflict: When two same-frequency cells are assigned the same PCI value, the user equipment may confuse and incorrectly connect to a neighboring cell instead of the correct primary service cell, and the resulting statistical indicator of incorrect connection events is the conflict MR number X. The formula is as follows:

$$X = \sum_{i=1}^{2067} \sum_{\substack{j=1 \\ j \neq i}}^{2067} a_{ij} x_{ipi} x_{jqj} \quad (1)$$

2) Confusion: When multiple neighbors of the same primary cell are assigned the same PCI, misjudgment may occur when the user equipment performs cell switching, resulting in connection to the wrong neighbor, which is known as PCI confusion, and the statistical index of the resulting incorrect connection events is the conflict MR number Y. The formula is as follows:

$$Y = \sum_{i=1}^{2067} \sum_{\substack{j=1 \\ j \neq i}}^{2067} b_{ij} x_{pi} x_{jqj} \quad (2)$$

3) Modulo-3 Interference (Modulo-3 Interference): When the master cell and its same frequency and overlapping coverage of the neighboring area assigned between the PCI value of Modulo-3 the same, due to the superposition effect of the reference signal, will lead to the user equipment received signal quality degradation CQI assessment error and network delay increases, this phenomenon is called PCI Modulo-3 Interference, the resulting false connection events of the statistical index is the conflict MR number Z, the formula is as follows. The statistical index of the resulting misconnections is the conflict MR number Z, which is given by the following equation.

$$Z = \sum_{i=1}^{2067} \sum_{\substack{j=1 \\ j \neq i}}^{2067} c_{ij} I\left(\left(PCI_j - PCI_i\right) \bmod 3 = 0\right) x_{ipi} x_{jqj} \quad (3)$$

where I am the indicator function. when $\left(PCI_j - PCI_i\right) \bmod 3 = 0$ is 1, otherwise it is 0.

2.2.2. Defining Decision Variables

For each cell I (i ∈ [1,2067]) and each possible PCI value j (j ∈ [0,1007]), Define a binary variablex_{ij},If cell i is assigned a PCI of j,$x_{ij} = 1$,if not x_{ij} =0.

2.2.3. Constructing the Objective Function

The objective function is constructed by minimizing the sum of all MR numbers due to conflicts [3], confusions and mode 3 interference minf (x) as below:

$$\min f(x)X = \sum_{i=1}^{2067}\sum_{\substack{j=1\\ j\neq i}}^{2067} a_{ij}x_{ipi}x_{jqj} + \sum_{i=1}^{2067}\sum_{\substack{j=1\\ j\neq i}}^{2067} b_{ij}x_{pi}x_{jqj} + \sum_{i=1}^{2067}\sum_{\substack{j=1\\ j\neq i}}^{2067} c_{ij}I\left(\left(PCI_j - PCI_i\right)\bmod 3 = 0\right)x_{ipi}x_{jqj} \quad (4)$$

Included among these,a_{ij}denotes the number of conflicting MRs between cell i and cell j; b_{ij}denotes the number of confusing MRs between cell i and cell j;

$c_{ij}I\left(\left(PCI_j - PCI_i\right)\bmod 3 = 0\right)$denotes the number of mode 3 interference MRs between cell i and cell j when their PCI mode 3 values are zero.

2.2.4. Constructing Constraints

1) Only one PCI is assigned per cell [4]:

$$\sum_{j=0}^{1007} x_{ij} = 1, \forall i\{1,2,3 \ldots \ldots 2067\} \quad (5)$$

2) The PCI assignment must be discrete, i.e., the binary variable can only take values of 0 or 1[5]:

$$x_{ij} \in (0,1), \forall i \in \{1,2, \ldots \ldots 2067\} \forall j \in \{1,2,3 \ldots \ldots 1007\} \quad (6)$$

3. Solving the PCI Planning Model

3.1. MR Optimization Model Solving based on Genetic Algorithm

1) Setting parameters:

The population size popsize is 10, the number of decision variables num_vars is 2067, and the number of binary bits per decision variable bits_per_var is 10, so the chromosome length chromlength equals num_vars * bits_per_var.

2) Set the genetic algorithm parameters:

Set the crossover probability pc to 0.6, the variance probability pm to 0.1, and the decision variable xlim from 0 to 1007. Create an empty array y to record the objective function value of the optimal individual in each generation. Generate a random initial population pop, and convert the binary code within the population to a decimal solution decpop to compute the objective function value fx of the initial population, and find the minimum value and the corresponding index by objective_function3.

3) Iterative process:

For each generation j (from generation 2 to generation G) perform the following steps:

Compute the objective function value fx for the current population decpop.

Calculate the fitness value fitvalue based on fx.

Perform a replication operation to retain some of the best individuals into the new population newpop.

Perform crossover operation on the new population and generate new offspring according to the crossover probability pc.

Perform a mutation operation on the new population to change the genetic value of some individuals according to the mutation probability pm.

Convert the mutated new population to the decimal solution newdecpop and calculate the objective function value new_fx for the new population.

Select individuals with lower (better) fitness values in the new population to replace the corresponding individuals in the original population, completing the selection process.

Update the population pop and the corresponding decimal solution decpop, and also calculate the objective function value of the updated population.

At the end of each generation, record the objective function value y(j) of the current optimal individual.

4) Termination conditions:

When the iteration reaches the preset maximum number of generations G, stop the iteration. Find the optimal objective function value ymin and its index min_index of the generation in the whole evolution process.

5) Output results:

Displays the objective function value ymin of the optimal solution obtained throughout the search.

3.2. Solution Results

According to the above model analysis, we solve the problem based on genetic algorithm, and finally the optimal solution is 55989824.The results of the solution are shown in Figure 2.

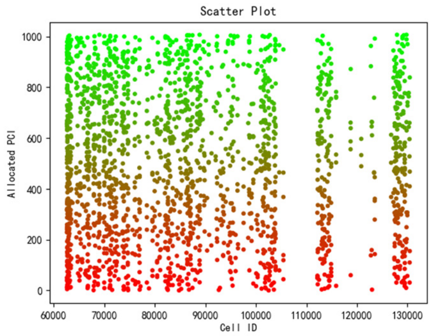

Fig 2. Visualization of the solution results

4. Conclusion

This study focuses on the importance of physical cell identifier (PCI) planning in large-scale mobile communication networks to reduce inter-cell conflicts, confusion and interference. Genetic algorithms are used to solve the PCI sequence optimization problem in wireless communication systems with the goal of reducing mobile reselection events caused by PCI conflicts, confusions and mode 3 interference. Iterative population selection, crossover and mutation operations are used to search and optimize PCI sequence configurations through a genetic optimization framework. Design PCI reallocation schemes for 2067 cells to minimize the sum of MR data points due to inter-cell conflicts, confusions and interference. Construct conflict matrix A, confusion matrix B, and interference matrix C. Determine inter-cell relationships and intensity metrics based on MR data to ensure that the total number of three MR data points is minimized under the new PCI plan. Conflict MR, confusion MR and mode 3 interference MR are optimized as decision variables, and the objective function is constructed to minimize the sum of interference MR, confusion MR and interference MR by adding them together, and solved by using the genetic optimization algorithm to ensure that the total number of MRs in 2067 cells is minimized. The optimal solution 55989824 is finally obtained through data processing, establishment of connectivity relationship network, integer planning model and genetic algorithm solution. This research result provides a strong support for optimizing network performance and improving user experience.

References

[1] Zhou Qi. Design and realization of PCI planning for LTE network in a city [D]. University of Electronic Science and Technology, 2020. DOI:10.27005/d.cnki.gdzku.2020.004895.

[2] Zhang Mingming. Research and application of spatial data organization analysis technology for mobile communication network coverage interference [D]. Beijing University of Posts and Telecommunications, 2020.DOI:10. 26969/d. cnki. gbydu. 2020. 000540.

[3] Bao-Ping Xia , An Overview of PCI Planning and Optimization for Base Station J]. Computer Knowledge and Technology. DO1: 10.14004/j.cnki.ckt.2023.1320.

[4] Liu X, Chen Yunguang, Liu Y. Exploration and practice of 5G wireless parameter self-optimization[J]. Guangdong Communication Technology, 2024,44 (03):2-7+47.

[5] Chen Shuang. AI-based wireless network planning and optimization solution[J]. Wireless Interconnection Technology, 2023, 0(13): 151-154+158.