Scrambling Code Planning for 3GPP W-CDMA Systems

Young-Ho Jung and Yong H. Lee
Korea Advanced Institute of Technology Department of EECS.
373-1 Kusong-dong, Yusong-gu, Taejon, 305-701, Korea
Email: yohlee@ee.kaist.ac.kr

Abstract

Two types of scrambling code planning methods for multi-layer asynchronous 3GPP W-CDMA systems are developed by modifying the PN offset planning methods for synchronous CDMA systems. One is based on the reuse of code sets and the other is based on the graph coloring optimization. A condition that guarantees no code set confusion is derived. Design examples demonstrate that the graph coloring based method can be more efficient than the reuse-based method, and applicable to a wide variety of real W-CDMA networks.

1. Introduction

In the 3GPP W-CDMA system, each sector (or base station) is distinguished by a scrambling code set which is assigned to it (a scrambling code set is composed of one primary scrambling code and 15 secondary scrambling codes) [1]. Assigning such a code set to each sector should be carefully planned depending on the sector size and propagation path loss of RF wave, because the number of cells in a W-CDMA network is usually much larger than the number of code sets, which is 512, and simultaneous use of the same code set for different sectors may cause scrambling code confusion.

In this paper, two types of scrambling code planning strategies are developed by modifying the PN offset planning methods for the IS-95 CDMA system. The first one, which will be referred to as the *cluster reuse-based* strategy, is based on the method in [2]; and the second one is a modification of the *graph coloring-based* method in [3]. It will be shown through some design examples that the graph coloring-based method yields more efficient scrambling code set planning than the cluster reuse-based method.

2. Scrambling code planning methods

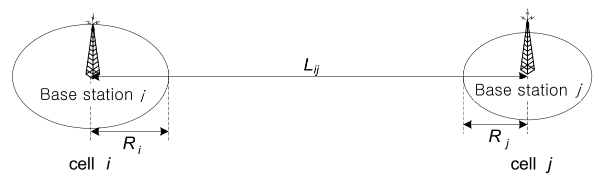

Figure 1. Two cells located L_{ij} apart.

A major task in scrambling code set planning is to determine the minimum distance between cells that can have an identical code set. This distance, which is referred to as the *reuse* distance, is derived as follows. Suppose that the i-th and j-th cells have an identical scrambling code set. Denote the distance between the cells by L_{ij} and the radii of these cells by R_i and R_j (Figure 1). The distance L_{ij} should be large enough so that signal power from a remote base station is much smaller than that from home base station. Specifically, it is desirable that the power from a remote base station is less than the noise power. This condition is satisfied if the following inequality is met:

$$10\log\left(L_{ij}-\max(R_i,R_j)\right)^{\alpha}-10\log\left(\max(R_i,R_j)\right)^{\alpha}$$
$$> PG_{dB} \qquad (1)$$

where α is the path loss exponent and PG_{dB} is the processing gain in dB scale. The first term in the left hand side of (4) represents the minimum propagation path loss of the remote base station signal and the second term is the maximum path loss of the home base station signal. The inequality in (4) is rewritten as

$$L_{ij} > \max(R_i, R_j) \cdot \left(1 + 10^{\frac{PG_{dB}}{10\alpha}}\right) \qquad (2)$$

The right hand side of (2) is the reuse distance between the i-th and j-th cells. The scrambling code planning methods will be developed using (2).

2.1. Cluster reuse-based method

Cluster reuse-based planning assigns code sets according to a code set reuse pattern, which is pre-determined. For example, in Figure 2, which shows uniform hexagonal cells, 13 cells are clustered and the pattern for code set assignment is repeated for all clusters. The reuse distance for the cluster reuse-based planning is obtained by replacing $\max(R_i, R_j)$ in (2) with $R_{\max}$ which is the radius of the largest cell; that is,

$$L > R_{\max} \cdot \left(1 + 10^{\frac{PG_{dB}}{10\alpha}}\right) \qquad (3)$$

where L is the distance between cells. Denote the number of cells in a cluster by K. Then, from [4], we can show that

$$L = R_{\min}\sqrt{3K} \qquad (4)$$

where $R_{\min}$ is the radius of the smallest cell. Using (4) in (3), a condition regarding the cluster size K is obtained:

$$K > \frac{R_{\max}^2}{3R_{\min}^2} \cdot \left(1 + 10^{\frac{PG_{dB}}{10\alpha}}\right)^2 \qquad (5)$$

To get a non-overlapping reuse pattern, K should be an element of the set $F = \{f(i,j) = i^2 + ij + j^2 | i, j$ are non-negative integers$\}$ [4]. Therefore, K is set to the smallest integer in F satisfying (5). The cluster size K is the number of code sets required by the network.

2.2. Graph coloring-based method

Graph coloring considers a problem of assigning a color to each node in a graph [4]. Suppose that there are colors with indexes $\{1, 2, \cdots\}$. Graph coloring minimizes the number of colors to be assigned under the constraint that the difference between color indexes assigned to the i-th and j-th node is larger than a constant c_{ij}, for all i and j. Since cells in a network can be thought of as nodes in a graph, graph coloring can be applied to the scrambling code planning problem that minimizes the number of scrambling code sets assigned to a network.

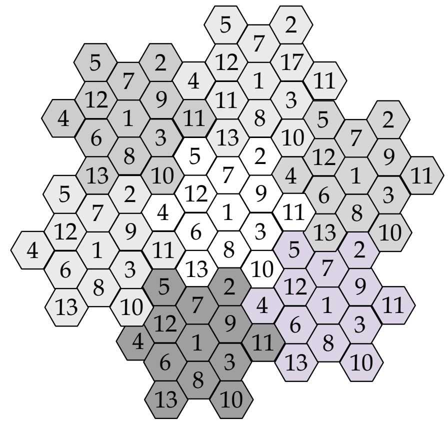

Figure 2. An example of cluster reuse-based scrambling code planning. The number assigned to each cell is the code index.

Suppose that there are M cells in a network. Let $X = \{1, 2, \cdots, M\}$ be the set of cell indexes, and $C = [c_{ij}]$ be an $M \times M$ matrix which is called the compatibility matrix. The constant c_{ij} is either zero or one: if the distance between the i-th and j-th cells is less than the reuse distance, in (2), c_{ij} is set to one; otherwise, c_{ij} is zero. Denote the number of available scrambling codes by z and the set of available code indexes by S. Let $S = \{1, 2, \cdots, z\}$. Our objective is to minimize z, under the constraints specified by the compatibility matrix C. Let I_{ki} be an indicator function that is equal to one if the k-th code index is assigned to the i-th cell, and zero, otherwise. Then $z = \max\{k | I_{ki} = 1\}$ and the graph coloring optimization problem for scrambling code planning problem is stated as follows

minimize

$$z = \max_{k \in S_l, i \in X_l} \{k | I_{ki} = 1\}$$

subject to

$$\begin{aligned} &\textstyle\sum_{k \in S} I_{ki} = 1 \text{ for all } i \in X, \\ &|k - n| \geq c_{ij} \text{ for all } k, n \in S \text{ and} \\ &i, j \in X \text{ satisfying } I_{ki} = I_{nj} = 1, \\ &I_{ki} = 0 \text{ or } 1. \end{aligned} \qquad (6)$$

The first constraint in (6) indicates that only one scrambling code set is assigned to a cell. The second constraint specifies that the code index separation between the i-th and j-th cells should be greater than or equal to c_{ij}.

It is well-known that the graph coloring problem in (6) is an NP complete problem. Therefore, it needs an exhaustive search for finding the optimal solution. To overcome this difficulty, several heuristic algorithms that yield sub-optimal solutions have been introduced [5]-[7]. The problem in (6) will be solved by using one of such algorithms, which has been applied to channel assignment for FDMA network [6],[7]. The algorithm is described as follows.

Step 1. For all i, $1 \leq i \leq M$, calculate d_i given by

$$d_i = \sum_{j=1}^{M} c_{ij} \tag{7}$$

(d_i is called the "assignment difficulty factor (ADF).")

Step 2. Index the cells according to the ADF so that the i-th cell is associated with the i-th largest ADF.

Step 3. A scrambling code set is assigned to the i-th cell, starting with $i = 1$ and increasing i one by one. The following is the procedure for scrambling code assignment.

- The 1st scrambling code index, the code index one is assigned to the 1st cell in the network $(i = 1)$.
- To the i-th cell, $2 \leq i \leq M$, the k-th code index is assigned if k is the minimum code index satisfying $|k - s_j| \geq c_{ij}$ for all j, $1 \leq j \leq i-1$, where s_j is the scrambling code index assigned to the j-th cell.

In this algorithm a cell with a large ADF takes priority of earlier assignment. In general, densely located cells have larger ADF values than sparsely located ones, because in a dense area there are many cells which do not meet the condition in (7). Therefore, the above algorithm tends to give priority to cells in a dense area.

2.3. Extension to a multilayered network

The cluster reuse and graph coloring-based methods can be directly applied to a multilayered network which consists of several layers such as macrocell-, microcell-, and picocell-layers. Scrambling code set planning for a single layer can be viewed as 2-dimensional (2-D) problem, and its extension to a multilayered is a 3-D problem. In the case of the cluster reuse-based strategy, such a 3-D problem degenerates into several 2-D subproblems, in which the number of subproblems is equal to that of layers, because disjoint scrambling code sets should be assigned to different layers. For the graph coloring-based strategy, such simplification does not occur – an identical code set may be used for different layers. In this case, we artificially simplifies the 3-D problem into 2-D problems, because solving a 3-D graph coloring problem is tedious. In summary, for both the cluster reuse-based and graph coloring-based methods, we propose to decompose 3-D planning into several 2-D planning problems, which use different code sets. Each 2-D problem is then solved by applying the methods in Sections 2.1 and 2.2. The decomposition of the 3-D planning into 2-D planning problems offers flexibility in multilayered network design: when a layer is either added or removed, it is not necessary to modify code sets of other existing layers.

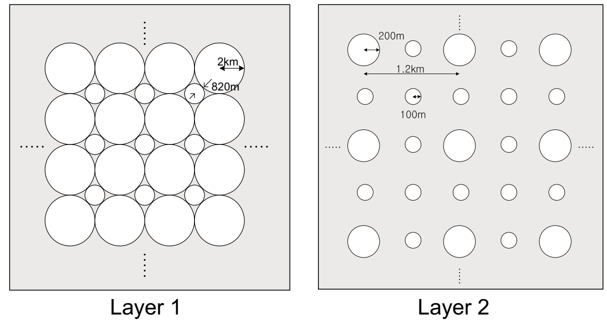

Figure 3. A CDMA network composed of two cell layers for example 1.

3. Scrambling code planning examples

In this section, efficiency of the proposed graph coloring-based method is demonstrated by some practical examples.

Example 1. Suppose that there are two-layered W-CDMA network distributed in a 100km × 100km area, as shown in Figure. 3. We assume that $\alpha = 3.5$ for layer 1 and $\alpha = 3$ for layer 2. If we apply the cluster reuse-based method, the minimum number of required scrambling code sets, K becomes 208 for layer 1, 217 for layer 2 and 425 in total. When the graph coloring-based method is used, the required scrambling code sets are: 18 for layer 1, and 16 for layer 2 and 34 in total.

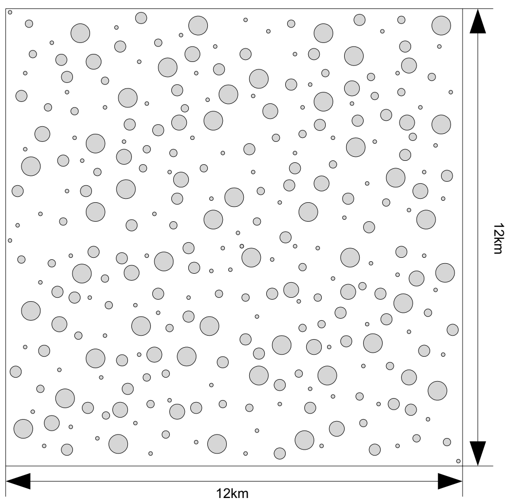

Figure 4. A CDMA network composed of 300 cells for example 2.

Example 2. Suppose that there are 300 microcells which are randomly distributed in a 100km $\times$ 100km area (Figure. 4). The radius of cells are from 100m to 500m. Applying cluster reuse-based method to this case indicates that 1344 scrambling code sets are required. In this case, the scrambling code planning is impossible, because there are only 512 code sets in W-CDMA. When the graph coloring-based method is used, the number of required scrambling code sets is 72.

References

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