PN offset Planning for Synchronous CDMA Based Fiber-Optic Microcellular Systems

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Abstract – PN offset planning methods for a multi-layer synchronous CDMA network composed of macrocells and fiber-optic microcells (fomicells) are developed. In these methods, planning of macrocells and that of fomicells are independently performed. For macrocells, an existing method, which is called the cluster reuse-based method, is used. For fomicells, it is observed that pre-compensation of optical delay is required at each base transceiver system (BTS) supporting fomicells. Two methods for fomicell planning are proposed. One is the cluster reuse-based method and the other is the graph coloring technique. Design examples indicate that the letter is more appropriate to fomicell environment and yields more efficient PN-offset planning than the former.

I. Introduction

In CDMA systems such as IS-95 [1] and IS-2000 [2], pilots from base stations are spreaded by PN sequences which are distinguished by distinct time shifts (or PN-offsets) of the basic PN sequence. To avoid any pilot confusion (or PN-offset confusion) in a CDMA network, assigning a PN-offset to each sector should be carefully planned depending on the sector size and the propagation delay of RF wave [3]-[5]. Obviously, PN-offset planning becomes more complex for a multi-layered network supporting both macrocells and microcells.

A CDMA network with fiber-optic microcellular systems [6],[7] is a simple multi-layered network. As shown in Fig.1, it consists of conventional base transceiver systems (BTSs) for macrocells and other BTSs for fiber-optic microcells (fomicells). Each fomicell is supported by a micro base station (mBS) which is connected to a BTS via optical cable. An mBS simply serves as a remote antenna of the BTS. When planning PN-offsets of a CDMA network with fomicells, the optical delay caused by the propagation through optical cable as well as the RF wave propagation delay should be considered. Furthermore, the fact that fomicells are usually island cells which are isolated from the other cells may be utilized for efficient planning.

In this paper, two types of PN-offset planning strategies for a CDMA network with fomicells will be introduced. The first one is based on the method in [3] which will be referred to as the cluster reuse-based strategy. The second will be derived by applying the graph coloring technique, which is used for channel assignment in a FDMA network [8]-[10], to PN-offset planning. It will be shown through design examples that the second strategy is more appropriate to fomicell environment and yields more efficient PN-offset planning than the first method. Throughout this paper, PN-offset planning strategies are designed for the IS-95 system.

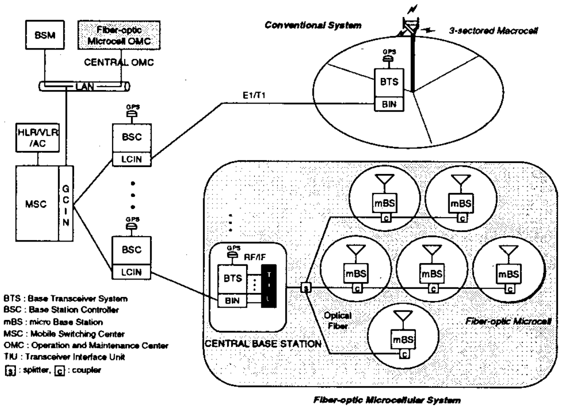

Fig. 1. A multi-layer CDMA network composed of conventional macrocell system and fiber-optic microcellular system.

II. Review of PN-offset Planning

In this section, we introduce fundamental concepts and terminologies regarding PN-offset planning and review the cluster reuse-based strategy in [3] which is developed for a nonuniform network with cells of different sizes.

In IS-95, multipath components of pilots are tracked by using search windows such as active, neighbor and remaining set search windows. Pilots in the active and neighbor sets are maintained for the forward link communication and handoff, respectively. The remaining set encompasses all possible pilots in the current system excluding those belonging to the other pilot sets. In the mobile station, usually three strongest signals in the active set search window are continuously tracked and combined by a RAKE receiver.

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There are two major considerations associated with PN-offset planning. One is the PN separation between two different PN-offsets used by adjacent cell sites. The other is the reuse distance between cells using identical PN-offsets. Pilot confusion caused by insufficient PN separation (reuse distance) is referred to as *adjacent* (*co-*) PN confusion [3]. IS-95 specifies that the minimum separation between two adjacent PN-offsets is 64chips, and there are 512 possible PN-offsets. When planning PN-offsets, to further reduce the chance of adjacent PN confusion, the minimum adjacent PN-offset separation is given by 64 × *PILOT_INC* where *PILOT_INC* is an integer which is greater than or equal to 1. The parameter *PILOT_INC* is determined under the following constraints:

- If the remote pilot countervails the PN-offset difference and get into the active set search window, due to large difference in propagation delay, then the remote pilot may be despreaded by one of the fingers of the RAKE receiver and obtain 21dB processing gain. To relieve the effect of the remote pilot in such a case, transmission path loss of the remote pilot should be 21dB larger than that of the home pilot.
- To avoid PN confusion during handoff, two adjacent neighbor set search windows should not overlap. Similarly, overlapping two adjacent remaining set search windows should be avoided.

PILOT_INC satisfying these constraints is given by

$$PILOT\_INC = \left\lceil \max\left\{ \frac{R_{\max} \times (10^{21/(10\alpha)} - 1)}{244}, W_N, W_R \right\} \Big/ 64 \right\rceil \quad (1)$$

where $R_{\max}$ is the radius of the largest cell; α is the propagation path loss exponent; 244 is the distance in the unit of meter that RF wave travels during one chip period (0.814μs); W_N and W_R denote spans of neighbor and remaining set search windows, respectively.

The co-PN confusion can be avoided if the remote pilot, using the same PN-offset as the home pilot, falls out of the active set search window. This condition is satisfied when the number of cells, say K, in a cluster meets the following inequality.

$$K > \left(\frac{W_A}{2} \times 244 + 2R_{\min} \right)^2 \Big/ 3R_{\min}{}^2 \quad (2)$$

where $R_{\min}$ is the radius of the smallest cell and W_A denotes the size of the active set search window. For uniform hexagonal cells, K should be an element of the set $F=\{f(i,j)=i^2+ij+j^2|\ i,j$ are nonnegative integers$\}$ [11]. Therefore, K is set to the smallest integer in F satisfying (2).

Finally, in this section we present an example indicating that the number of PN-offsets required for practical PN-offset planning is much smaller than 512. This fact is useful for PN-offset planning of fomicells.

Example 1. Suppose that $R_{\max} = 8$km, $R_{\min} = 1$km, $W_A = 40$chips, $W_N = W_R = 60$chips and α=3.3. From (1) and (2), *PILOT_INC*=2 and K=16. If each cell has 3 sectors, then the total number of PN-offsets required for PN-offset planning becomes 3×*PILOLT_INC*×K=96.

The radii considered in this example are typical values of macrocells. The PN-offsets which are not employed in macrocell planning can be used for fomicell planning, as described in the following section.

III. PN-offset Planning for A Network with Fiber-optic Microcells

A. Use of Cluster reuse-based Strategy

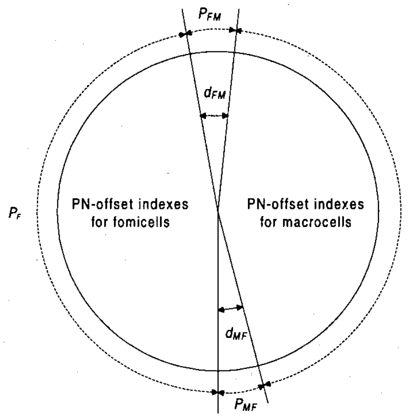

Fig. 2. Grouping PN-offsets for macrocells and fomicells. The circle represents total available PN-offsets; d_{MF} and d_{FM} are guard intervals.

Since only a portion of 512 PN-offsets are usually employed in macrocell planning, these 512 PN-offsets denoted by the set of indexes P={0, 1, 2, ..., 511} can be decomposed into the following four disjoint groups (Fig.2): $P = P_M \cup P_{MF} \cup P_F \cup P_{FM}$ where P_M and P_F are sets of PN-offset indexes for macrocells and fomicells, respectively; P_{FM} and P_{MF} are sets of PN-offset indexes which serve as guard intervals preventing pilots from PN confusion between macrocells and fomicells. Assuming that the guard intervals are large enough for avoiding the PN confusion, PN-offset planning for macrocells and that for fomicells can be independently performed. Specifically, PN-offsets for macrocells can be planned by using (1) and (2), ignoring the existence of fomicells. For PN-offset planning of fomicells (1) and (2) can also be used, but in this case optical delay should be pre-compensated at a BTS by transmitting a PN-offset which is advanced by the period of expected optical delay. (In fomicells the distance between BTS and mBS is known, and thus optical delay can be accurately measured.) For example, if the PN-offset of an mBS is 256 chips and the optical delay is 16 chips, then the BTS transmits the PN code with offset of 240 chips. After the pre-compensation, *PILOT_INC* and K for fomicells are obtained from (1) and (2). Finally, the guard intervals between P_M and P_F are determined as follows. If we denote the numbers of PN-offset indexes in P_{MF} and P_{FM} by d_{MF} and d_{FM}, respectively, then

$$d_{MF} = d_{FM} = PILOT\_INC \text{ of macrocells.} \qquad (3)$$

Since *PILOT_INC* of macrocells is always larger than that of fomicells, d_{MF} and d_{FM} determined in (3) prevent pilots from PN confusion between macrocells and fomicells. The following example illustrates PN-offset planning for a network with fomicells.

Example 2. Suppose that PN-offset planning for macrocells are performed as in Example 1. For fomicells, we assume that $R_{\max}$=2km, $R_{\min}$=350m and that the other parameters are the same as those in Example 1. From (1) and (2), *PILOT_INC*=1 and *K*=91. Since a fomicell has only one sector, the total number of PN-offsets required for planning PN-offsets of fomicells becomes *PILOLT_INC*×*K*=91. The guard interval parameters d_{MF} and d_{FM} are equal to 2 and the total number of PN-offset indexes required for planning the overall network is: 96 + 2 + 91 + 2 = 191.

From (2), it is noted that K increases exponentially as $R_{\min}$ decreases. In Example 2, if $R_{\min}$ for fomicells is reduced to 148m, then K becomes 409. Therefore, in this case the total number of PN-offsets for planning both macrocells and fomicells is 512. The total number exceeds 512 when $R_{min} <$ 148m, and thus the cluster reuse-based strategy cannot be used for such cases. An intuitive reason why K increases so rapidly is that the cluster reuse-based strategy assumes densely located cells. The graph coloring technique which is described next can be applied to island cells, and can be more efficient to fomicell planning than the cluster reuse-based strategy.

B. Use of Graph Coloring Method

In this subsection, graph coloring is applied to fomicell planning. It is assumed that macrocells are planned by using the cluster reuse-based strategy, and that pre-compensation of optical delay is achieved at BTSs supporting fomicells.

Graph coloring considers a problem of assigning a color to each node in a graph [12]. Suppose that those are colors with indexes {0, 1, 2, ...}. 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 PN-offset planning problem that minimizes the number of PN-offsets assigned to a network. Details of graph coloring for PN-offset planning are described below.

Suppose that there are N fomicells in a network[1]. Let X={1, 2, ..., N} be the set of cell indexes, and $C=[c_{ij}]$ be an $N \times N$ matrix which is called the compatibility matrix. Its element c_{ij} is a nonnegative integer specifying the minimum PN-offset separation between the i-th and j-th cells. The set of PN offset indexes for fomicells, P_F, is given by $P_F=\{1, 2, \ldots, z\}$ where z is a positive integer representing the number of PN-offsets required for fomicell planning. 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 PN-offset index is assigned to the i-th cell, and zero, otherwise. Then, $z = \max_{k\in P, i\in X}\{k \mid I_{ki}=1\}$ and the optimization problem is stated as follows:

$$\begin{aligned}
&\textit{minimize} \\
&\max_{k\in P, i\in X}\{k \mid I_{ki}=1\} \\
&\textit{subject to} \\
&\sum_{k\in P} I_{ki} = 1 \qquad \text{for all } i\in X \qquad\qquad (3) \\
&|k-l| \geq c_{ij} \\
&\qquad \text{for all } k,l\in P_F \text{ and } i,j\in X \text{ satisfying } I_{ki}=I_{lj}=1 \\
&I_{ki} = 0 \text{ or } 1 \qquad \text{for all } k\in P_F \text{ and } i\in X
\end{aligned}$$

The first constraint in (3) indicates that only one PN-offset is assigned to a cell. The second constraint specifies that the PN-offset separation between the i-th and j-th cells should be greater than or equal to c_{ij}. Of course, the parameter c_{ij} should be determined so that pilot confusion can be avoided. To assign an identical PN-offset to the i-th and j-th cells, the distance between the i-th and j-th cells, which is denoted by L_{ij} should be large enough. Specifically, referring to Fig.3, the pilot from the j-th cell falls out of the active search window of the i-th cell if

$$\frac{(L_{ij}-R_i)}{244} - \frac{R_i}{244} > \frac{W_A}{2}. \qquad (4)$$

Similarly, for the j-th cell

$$\frac{(L_{ij}-R_j)}{244} - \frac{R_j}{244} > \frac{W_A}{2}. \qquad (5)$$

Combining (4) and (5) and rearranging yields

$$L_{ij} > (W_A/2)\times 244 + 2\cdot\max\{R_i, R_j\}. \qquad (6)$$

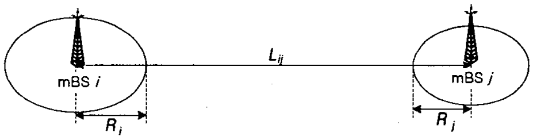

Fig. 3. Two fomicells located L_{ij} meter apart.

If L_{ij} meets (6), then c_{ij} can be set at zero, because there is no risk of co-PN confusion between the i-th and j-th cells. On the other hand, if (6) is not satisfied, then the i-th and j-th cells should have different PN-offsets. In this case, adjacent PN-offset confusion can be avoided if c_{ij} is given by

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[1] When using graph coloring, all fomicells in a network are simultaneously considered. PN offsets can be individually reused, but the concept of cluster reuse is not applied.

$$c_{ij} = \left\lceil \max[\max\{R_i, R_j\} \times (10^{21/(10\alpha)} - 1)/244, W_R, W_N]/64 \right\rceil . \quad (7)$$

Note that (7) is obtained from (1) by replacing R_{max} in (1) with $\max\{R_i, R_j\}$. Summarizing, the parameter c_{ij} is given by

$$c_{ij} = \begin{cases} 0 & \text{if (6) is satisfied} \\ (7), & \text{otherwise.} \end{cases} \quad (8)$$

It is well-known that the graph coloring in (3) 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 [8]-[10]. The problem in (3) will be solved by using one of such algorithms, which has been applied to channel assignment for FDMA network [9],[10]. The algorithm is described as follows.

Step 1. For all i, $1 \le i \le N$, calculate d_i given by

$$d_i = \sum_{j=1}^{N} c_{ij} \quad (9)$$

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

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

Step 3. PN-offset is assigned to the i-th fomicell, starting with i=1 and increasing i one by one. The following is the procedure for PN-offset assignment.

- The 1st PN-offset is assigned to the 1st fomicell (i=1).
- To the i-th fomicell, $2 \le i \le N$, the k-th PN-offset is assigned if k is the minimum PN-offset index satisfying

  $$|k - p_j| \ge c_{ij}$$

  for all j $1 \le j \le i$-1, where p_i is the PN-offset index assigned to the j-th fomicell.

In this algorithm a cell with a large ADF takes priority of earlier assignment. In general, densely located fomicells have larger ADF values than sparsely located ones, because in a dense area there are many cells which do not meet the condition (6). Therefore, the above algorithm tends to give priority to fomicells in a dense area.

The following example demonstrates the advantage of graph coloring over the cluster reuse-based method.

Example 3. Suppose that there are 100 fomicells which are randomly distributed in 3.3kmx3.3km square area (Fig. 4). The radius of each fomicell is 100m. The spans of search window and the propagation loss parameter α remain the same as those in Example 1. Since the fomicells have identical sizes, c_{ij} in (7) is fixed at 1. Therefore, the compatibility matrix C is a 100×100 matrix consisting of 0's and 1's. Applying the exhaustive PN search algorithm to this case indicated that 101 PN offsets were required for fomicell planning. When the cluster reuse-based strategy was used, the number of required PN offsets was 567 (*PILOT_INC*=1, *K*=567). Obviously, graph coloring outperformed the cluster reuse-based method. Although the former needed more computation than the latter, it indeed yielded very efficient PN-offset planning for fomicells.

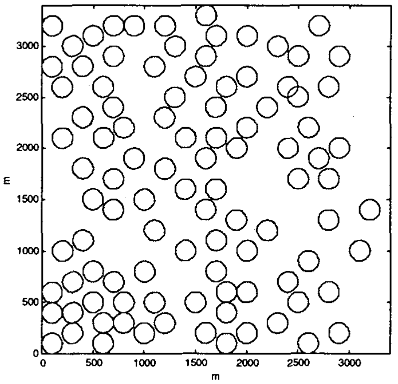

Fig. 4. Fiber-optic microcells for PN-offset planning Examples 3

VI. Conclusion

In this paper, we proposed two PN-offset planning methods for the multi-layer CDMA network composed of macrocells and fomicells. Between the two methods, the graph coloring technique was more appropriate to planning fomicells, which are inherently island cells, than the cluster reuse-based method.

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