### Scrambling Code Planning in TD-SCDMA Cellular Systems

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SCRAMBLING CODE PLANNING IN TD-SCDMA CELLULAR SYSTEMS

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Abstract

Scrambling code planning (SCP) for TD-SCDMA systems is a challenging issue due to the poor cross correlations between the spreading codes generated by cell-specific scrambling codes. In this paper, a novel SCP algorithm is proposed. Inter-cell interference is modeled as a function of not only the cross correlations between spreading codes, but also the radio propagation conditions and traffic distributions. The cross correlation of spreading codes is analyzed, and a concept of scrambling code family is proposed to simplify the code planning process. The proposed algorithm facilitates the assignment and selection of scrambling codes. Numerical results shows that the proposed algorithm can achieve a much lower inter-cell interference than the existing SCP algorithms.

Index Terms

Scrambling code planning; TD-SCDMA; inter-cell interference; scrambling code family

I. INTRODUCTION

As one of the major 3G cellular systems, TD-SCDMA has been deployed in the mainland China for large-scale commercial applications [1]. However, its network planning techniques are less mature than those of WCDMA and cdma2000 [2]. Especially, scrambling code planning (SCP) for TD-SCDMA is a challenging issue. Every cell in TD-SCDMA systems should be assigned one scrambling code to scramble data and distinguish itself from its neighboring cells [3]. The SCP is to assign scrambling codes to all cells properly in order to minimize inter-cell interference over the whole network, while still ensuring every cell to be distinguishable. However, the length of the scrambling codes of TD-SCDMA is only 16 chips, resulting in a strong inter-cell interference. Moreover, the algebraic structure of the scrambling codes is unknown because all 128 scrambling codes are given in a table in 3GPP standard [3], making correlation and interference analysis very difficult. Besides, the scrambling codes assigned to a geographically adjacent cell pair have to be selected from different code groups [3] to avoid confusion of SYNC-DL (downlink synchronization) sequences, while there are only 32 code groups. Therefore, the SCP in TD-SCDMA systems becomes an extremely difficult task.

There have been many SCP algorithms proposed for TD-SCDMA. They can be classified into three major categories, including cluster reuse based algorithms (CRAs), code compatibility based
algorithms (ECAs), and interference metric based algorithms (IMAs). CRAs perform simple SCP by reusing scrambling codes among all the cells with a given reuse pattern [2]. In ECAs, two scrambling codes are considered incompatible and will not be assigned to adjacent cells if the cross correlations between the spreading codes generated from them exceed a given threshold [4]. IMAs uses the cross correlation between spreading codes as a metric of inter-cell interference, thus formulating SCP as an optimization problem to minimize the total inter-cell interference over a network [5]. All the existing SCP algorithms have chosen some cross correlation related metric, such as the extremum or the mean of cross correlations between spreading codes, assuming that inter-cell interference is dependent only on the codes. All of them ignored the other influencing factors, such as radio propagation conditions. Besides, all the existing works focused on the cross correlation functions of real-valued spreading codes, without considering the fact that complex-valued spreading codes are adopted in TD-SCDMA.

In this paper, SCP issues in TD-SCDMA are revisited. To characterize its generation mechanism accurately, inter-cell interference is expressed as a function of not only cross correlation between spreading codes, but also radio propagation conditions and traffic distribution. The complex-valued spreading codes and their cross correlation function are discussed. Scrambling code family is defined and an interference equivalence theorem is proposed to reveal the inherent relationship among scrambling codes in the same family. Based on the theorem, an SCFA-SCS algorithm is proposed for accomplishing SCP in two steps at a much lower computational complexity than that of the existing SCP algorithms.

The remainder of the paper is outlined as follows. Inter-cell interference is analyzed and its expression is derived in Section II. The scrambling code families and interference equivalence theorem are proposed in Section III. The SCFA-SCS algorithm for SCP problem is described and discussed explicitly in Section IV. Numerical results are presented in Section V, followed by the conclusions drawn in Section VI.

II. INTER-CELL INTERFERENCE MODEL

In this section, a proper metric to measure inter-cell interference is established first, and then the interference model is proposed. Our discussions focus on the downlink, since the uplink
inter-cell interference is usually relatively weak due to the limited transmit power of terminals.

### A. Interference to Signal Ratio

Interference to signal ratio (ISR) is adopted in this work as a metric to measure the interference level. ISR is the reciprocal of signal to interference ratio (SIR), which is a commonly used metric reflecting wireless link quality. ISR between a serving signal and the combination of all interfering signals equals to the sum of all ISRs between the serving signal and every interfering signal. The use of this metric simplifies interference modeling.

### B. Network Level ISR

In a cellular network, let us define ISR of the network (abbreviated as ISR-N) as the sum of all ISRs between cell pairs, or

$$ I \triangleq \sum_{p=1}^{M} \sum_{q=1,q\neq p}^{M} I_{p,q}^{s_p,s_q}, $$

(1)

where $M$ is the number of cells in the network, cell index is $p, q = 1, 2, \ldots, M$, and $I_{p,q}^{s_p,s_q}$ is the ISR between the $p$-th cell (the serving cell) using scrambling code $s_p$, and the $q$-th cell (an interfering cell) using scrambling code $s_q$.

### C. Inter-cell ISR

The inter-cell ISR $I_{p,q}^{s_p,s_q}$ is defined as a traffic-weighted sum of ISRs of all users served by the $p$-th cell within a given period of time (usually several weeks), or

$$ I_{p,q}^{s_p,s_q} \triangleq \int_{(x,y) \in \mathcal{R}_p} G_{s_p,s_q}(\eta_{p,q}^{x,y}, \tau_{p,q}^{x,y}) e_p(x,y) \, dx \, dy, $$

(2)

where $(x, y)$ is the location of a user in the $p$-th cell, $\mathcal{R}_p$ is the geographical coverage area of the $p$-th cell, $\eta_{p,q}^{x,y}$ and $\tau_{p,q}^{x,y}$ are the carrier to interference ratio (CIR) and the delay between signals of the $p$-th cell and $q$-th cell, respectively. $G_{s_p,s_q}(\eta_{p,q}^{x,y}, \tau_{p,q}^{x,y})$ is the ISR of the user, i.e., the ISR experienced by the user in the worst case (see Appendix for its definition and mathematical formulation). $e_p(x,y)$ is the traffic density at $(x,y)$; its integration over certain region is the traffic volume occurred in the region, and it gives a larger weight to the location with a heavier traffic.
After variable substitution in Eq. (2), $I_{p,q}^{s_p,s_q}$ can be expressed as a function of CIR $\eta$ and delay $\tau$, that is

$$I_{p,q}^{s_p,s_q} = \Omega_p \int_{(\eta,\tau)\in\Theta_{p,q}} G_{s_p,s_q}(\eta, \tau) e'_p(\eta, \tau) f_{p,q}(\eta, \tau) \, d\eta \, d\tau,$$

where $\Omega_p$ is the area of $\Re_p$, $\Theta_{p,q}$ is the value range of $(\eta,\tau)$ in the $p$-th cell, and $f_{p,q}(\eta, \tau)$ is the joint probability density function of $(\eta, \tau)$ over $\Re_p$, which is determined by the radio propagation conditions between two cells and BS transmitting powers of both cells. $G_{s_p,s_q}(\eta, \tau)$ and $e'_p(\eta, \tau)$ are the ISR of a user and traffic density at $(\eta, \tau)$, respectively. Compared to Eq. (2), Eq. (3) can be calculated because $G_{s_p,s_q}(\eta, \tau)$ can be expressed explicitly as a function of CIR and the cross correlation between the spreading codes (see Eq. (A.5) for details).

According to Eqs. (3) and (A.5), $I_{p,q}^{s_p,s_q}$ depends on the radio propagation conditions between two cells, traffic distribution (containing user distribution information), and the cross correlation between the spreading codes generated from the scrambling codes assigned to the cell pair.

III. SCRAMBLING CODES AND INTERFERENCE EQUIVALENCE THEOREM

The cross correlation of spreading codes is a critical factor governing the inter-cell ISR $I_{p,q}^{s_p,s_q}$, and thus is discussed in detail in this section.

A. Spreading codes and their cross correlation functions

The procedure of spreading modulation in a TD-SCDMA system [3] is depicted in Fig. 1. The cascade of channelization and scrambling on data-streams can be viewed as the spreading operation on the data-streams with a spreading code.

In TD-SCDMA downlink, the spreading factor $N$ of a traffic channel is either 16 or 1. $N=16$ is considered in this paper because traffic channel with $N=1$ is seldom used. With $N = 16$, the spreading codes for different data symbols are the same since the lengths of scrambling codes and channelization codes are 16. Therefore, a spreading code is obtained by symbol-wise multiplying a channelization code with a scrambling code, i.e.,

$$c_{p,a} = s_p \odot w_a,$$
where \( s_p = (s_{p,1}, s_{p,2}, \ldots, s_{p,16})^T \) is a scrambling code of length 16, and "\( \odot \)" is a Hadamard multiplication operator [6]. The \( a \)-th channelization code \( w_a \) (where \( a = 1, 2, \ldots, 16 \)) is generated through the complexification of a real-valued channelization code, or

\[
w_a = (w_{a,1}, w_{a,2}, \ldots, w_{a,16})^T = \varepsilon_a \hat{w}_a,
\]

where \( \varepsilon_a \) is the complexification factor for \( \hat{w}_a \) as listed in Table I, and \( \hat{w}_a \) is the original real-valued channelization code of \( w_a \). The 16 original real-valued channelization codes are OVSF (Orthogonal Variable Spreading Factor) codes.

B. Scrambling Code Family

The scrambling codes can be classified into several families, and the scrambling codes in a family carry inherent equivalence, which can be explored to simplify SCP. First, let us give the definition of a scrambling code family. For any two scrambling codes, \( s_p \) and \( s_p' \), they belong to the same scrambling code family if they satisfy \( s_p' = \pm s_p \odot \hat{w}_k \), where \( \hat{w}_k \) is one of the original real-valued channelization codes.

For any two scrambling codes, \( s_p' \) and \( s_p \), belonging to the same family, there exists a one-to-one correspondence between their spreading code sets, or

\[
c_{p,a} = s_p \odot w_a = \pm s_{p'} \odot \hat{w}_k \odot w_a = \pm s_{p'} \odot \left( \varepsilon_a \hat{w}_l \right) = \pm \frac{\varepsilon_a}{\varepsilon_l} s_{p'} \odot w_l = \pm \frac{\varepsilon_a}{\varepsilon_l} c_{p',l},
\]

where \( \varepsilon_a \) and \( \varepsilon_l \) are the complexification factors of \( w_a \) and \( w_l \), respectively. The third equality holds because the Walsh codes of the same length form an abstract group [8], and thus \( \hat{w}_k \odot \hat{w}_a = \hat{w}_l \).
The cross correlation between the spreading codes $c_{p,a}$ and $c_{q,b}$ generated by any other scrambling code $s_q$ can be derived as (assume $\delta > 0$ without loss of generality)

$$r_{p,q}^{a,b}(\delta) = (Q_\delta c_{p,a})^H c_{q,b} = \left(\pm \frac{\varepsilon_a}{\varepsilon_l}\right)^* (Q_\delta c_{p',\ell})^H c_{q,b} = \left(\pm \frac{\varepsilon_a}{\varepsilon_l}\right)^* r_{p',q}^{l,b}(\delta),$$

(9)

where $r_{p',q}^{l,b}(\delta)$ is the cross correlation between $c_{p',\ell}$ and $c_{q,b}$. It can be seen that $r_{p,q}^{a,b}(\delta)$ and $r_{p',q}^{l,b}(\delta)$ have the same magnitude as $\pm (\varepsilon_a/\varepsilon_l)$ takes a value from $\{1, -1, j, -j\}$, and there exists a bijective mapping between them. It means that for different scrambling codes in a family, the distributions of their cross correlation levels are identical.

According to the definition of scrambling code family, all 128 scrambling codes in a TD-SCDMA system can be classified into 12 families, as presented in Table II. The scrambling codes of each family come from at least four different code groups. The scrambling code ID and the code group ID in Table II are the IDs specified in 3GPP standard [3].

C. Interference Equivalence Theorem

According to the property of identical cross correlation distribution, we can describe an inherent equivalence among all scrambling codes in a family by proposing the interference equivalence theorem as follows.

**Interference Equivalence Theorem:** Assume that $T_p$ and $T_q$ are any two scrambling code families. For the scrambling codes $s_p, s_{p'} \in T_p$ and $s_q \in T_q$, we always have $I_{p,q}^{s_p,s_q}(\eta, \tau) = I_{p,q}^{s_{p'},s_q}(\eta, \tau)$.

This theorem can be proved directly by substituting Eq. (9) into Eqs. (A.3), (A.2), (A.5) and Eq. (3). It reveals that a scrambling code assigned to a cell can be replaced by any scrambling code from the same family, while the ISR between a cell pair remains the same.

IV. SCRAMBLING CODE PLANNING

It can be seen from Eq. (4) that the spreading code set of a cell depends only on the scrambling code of that cell, because channelization code sets in different cells are identical OVSF code set that is actually a Walsh code set. This tells why SCP scheme has a strong influence on inter-cell interference, and why SCP is critical to TD-SCDMA systems.
Inspired by the Interference Equivalence Theorem, a novel SCP algorithm is proposed in this section. It consists of two steps: (1) scrambling code family assignment (SCFA), i.e., assign scrambling code families to cells to minimize the inter-cell interference in the network; (2) scrambling code selection (SCS), i.e., select one scrambling code for every cell from its scrambling code family under the constraint that scrambling codes from the same code group can not be assigned to its adjacent cells. Thus, we get the SCFA-SCS algorithm.

A. SCFA

To find a proper scrambling code family assignment scheme to minimize the inter-cell interference in the whole TD-SCDMA network, SCFA is formulated as

\[
\min \sum_{p=1}^{M} \sum_{q=1, q \neq p}^{M} I_{p,q}^{T_p, T_q}, \quad (10-a)
\]

\[
\text{s.t.} \quad T_p, T_q \in \Pi, \quad (10-b)
\]

where \( \Pi \) is a set of the scrambling code families, \( T_p \) and \( T_q \) are the scrambling code families used by the \( p \)-th and \( q \)-th cells, respectively, and \( I_{p,q}^{T_p, T_q} \) is the ISR between the \( p \)-th and \( q \)-th cells. Thus, we get

\[
I_{p,q}^{T_p, T_q} = I_{p,q}^{s_p, s_q} = \Omega_p \int_{(\eta, \tau) \in \Theta_{p,q}} G_{T_p, T_q}(\eta, \tau) f_{p,q}(\eta, \tau) e^{i \phi(\eta, \tau)} d\eta d\tau, \quad \forall s_p \in T_p, s_q \in T_q, \quad (11)
\]

where \( G_{T_p, T_q}(\eta, \tau) \) is the ISR of a user, and \( G_{T_p, T_q}(\eta, \tau) = G_{s_p, s_q}(\eta, \tau), \quad \forall s_p \in T_p, s_q \in T_q \).

The SCFA problem can be expressed as a 0-1 quadratic programming problem, or

\[
\min_{z} z^T \Gamma z, \quad (12-a)
\]

\[
\text{s.t.} \quad z = [z_{1,1}, z_{1,2}, \ldots, z_{1,12}, z_{2,1}, z_{2,2}, \ldots, z_{p,d}, \ldots, z_{M-1,12}, z_{M,1}, z_{M,2}, \ldots, z_{M,12}]^T, \quad (12-b)
\]

\[
z_{p,d} = 0 \text{ or } 1 \quad (12-c)
\]

\[
\sum_{d=1}^{12} z_{p,d} = 1, \quad p = 1, 2, \ldots, M, \quad d = 1, 2, \ldots, 12, \quad (12-d)
\]

where \( z \) in Eq. (12-b) is an assignment vector that denotes a scrambling code family assignment scheme, and \( z_{p,d} \) in Eq. (12-c) is an assignment variable equal to one if the \( d \)-th scrambling code family is assigned to the \( p \)-th cell, or equals to zero otherwise. Eq. (12-d) is a constraint
that each cell can be assigned one and only one scrambling code. $\Gamma$ in Eq. (12-a) is an ISR matrix containing all possible ISRs in any cell pair in the network, defined as

$$\Gamma = [\Gamma_{p,q}]_{M \times M}. \quad (13)$$

Its sub-matrix at the $p$-th row and $q$-th column is

$$\Gamma_{p,q} = \begin{pmatrix} \gamma_{1,1}^{p,q} & \gamma_{1,2}^{p,q} & \ldots & \gamma_{1,12}^{p,q} \\ \gamma_{2,1}^{p,q} & \gamma_{2,2}^{p,q} & \ldots & \gamma_{2,12}^{p,q} \\ \ldots & \ldots & \ldots & \ldots \\ \gamma_{12,1}^{p,q} & \gamma_{12,2}^{p,q} & \ldots & \gamma_{12,12}^{p,q} \end{pmatrix}, \quad p, q = 1, 2, \ldots, M, \ p \neq q, \quad (14)$$

which contains all possible ISRs between the $p$-th and $q$-th cells when different scrambling code families are assigned to these two cells. Obviously, the sub-matrices at the diagonal line $\Gamma_{p,p}$ are zero matrices. The element $\gamma_{p,q}^{h_p,h_q}$ at the $h_p$-th row and the $h_q$-th column of $\Gamma_{p,q}$ is the ISR between the $p$-th and the $q$-th cells when scrambling code families $T_p$ and $T_q$ are assigned to them, or

$$\gamma_{p,q}^{h_p,h_q} = I_{p,q}^{T_p,T_q}, \quad h_p, h_q = 1, 2, \ldots, 12, \quad (15)$$

where $h_p$ and $h_q$ are the IDs of the scrambling code families $T_p$ and $T_q$, respectively.

The 0-1 quadratic programming problem is a typical NP-complete problem [9]. It can be solved approximately using a semidefinite relaxation method [10]. For the planning of a practical large-scale network, evolutionary algorithm is a commonly used heuristic algorithm [11].

To obtain $\Gamma$ that is needed for solving the problem defined in (12), we developed a method to calculate $I_{p,q}^{T_p,T_q}$ in Eq. (11) from Mobile Measurement Report (MMR) data of a practical network. It is to calculate $I_{p,q}^{T_p,T_q}$ approximately by expressing the integration in Eq. (11) as the sum of integrations over many CIR-delay sub-regions.

**B. SCS**

The task of SCS is to select a scrambling code for each cell from the assigned scrambling code family of that cell. It is commonly known that to avoid mutual interference, adjacent cells should have different synchronization sequences. Since any single SYNC-DL sequence is bounded with...
four scrambling codes in a code group [3], there is a constraint in SCS that the scrambling codes
assigned to adjacent cells should be from different code groups.

In fact, for any code family, there are at least four associated code groups (as shown in Table II). Therefore, according to the famous Four Color Theorem in graph theory, there must be a feasible SCS scheme satisfying the constraint and it can be obtained through any graph coloring techniques.

C. Complexity of SCFA-SCS Algorithm

The computational complexity of this two-step algorithm is $O(12^M) + O(14^M)$ if solved by an exhaustive approach, where $M$ is the number of cells, 12 is the number of scrambling code families, and 14 is the maximal number of the code groups associated with a scrambling code family (i.e., Family 2). Therefore, the complexity is much lower than that of any traditional SCP algorithm whose complexity is $O(128^M)$.

V. NUMERICAL RESULTS

Numerical results are given in this section to evaluate the performance of the proposed SCFA-SCS algorithm.

A. Parameter Settings

The parameters used in numerical calculations are listed in Table III. In our numerical calculations, ISR-N of each scenario was obtained by averaging ISRs over 100 layouts, and these 100 different layouts have the same minimum distance threshold and/or traffic density. Two types of layouts were adopted. With a uniform hexagonal layout, the radio propagation conditions are identical so that the impact of traffic distribution can be observed clearly. In contrast, with an irregular layout, the influence of radio propagation condition can be observed easily. $\lambda$ MMRs are reported by a user in a heavy-traffic cell whenever one MMR is reported by a user in a normal-traffic cell. Here, $\lambda$ is the traffic density ratio.

A graph-based algorithm proposed in [5] (referred to as clique algorithm) was also simulated for performance comparison, which is a typical SCP algorithm among all those using interference
metric. It selects a subset of scrambling codes with relatively weak cross correlations, according to a given tolerable cross correlation level, maximum delay, and interference metric threshold. Then, the scrambling codes in the selected subset are assigned to the cells under the constraint that the scrambling codes of adjacent cells must belong to different code groups.

B. ISR-N versus Traffic Density Ratio

In the uniform hexagonal layouts, ISR-Ns under different traffic density ratios are shown in Fig. 2. It can be found that the ISR-Ns resulted from using the proposed SCFA-SCS algorithm are always lower than those using the clique algorithm, and the gap between them becomes larger as the traffic density ratio increases. It verifies that the scrambling code planning taking traffic distribution into consideration can achieve a better performance.

C. ISR-N versus Minimum Distance Threshold

The ISR-Ns with irregular layouts under different minimum distance thresholds are shown in Fig. 3. It is observed that ISR-N increases as the minimum distance threshold decreases. This is due to the fact that the more irregular the deployment of BSs is, the severer the inter-cell interference becomes. It can also be observed that the ISR-Ns resulted from using SCFA-SCS algorithm are always much lower than those using the clique algorithm. These two observations reveal the fact that scrambling code planning is able to achieve a satisfactory performance only if the impact of radio propagation condition on the inter-cell interference is considered. Moreover in Fig. 3, as the minimum distance threshold increases, the resulted ISR-N gets closer to the ISR-N obtained in a uniform hexagonal layout scenario with traffic density ratio $\lambda = 1$ (as illustrated in Figure 2) since the irregular layout is getting closer to the uniform hexagonal layout.

VI. CONCLUSIONS

A SCP algorithm has been proposed in this paper. The ISR was selected as a metric to measure inter-cell interference severity since it is an indicator of wireless link quality and is easy to analyze. The ISR of a cell pair was modeled as a function of not only cross correlation between spreading codes, but also radio propagation condition and traffic distribution so that
ISR-N can be minimized for a specific application scenario. The cross correlation of a spreading code set generated from a scrambling code was studied. In total 128 scrambling codes were classified into 12 families, according to the relationship between their spreading code sets. The scrambling codes in the same family were found to be interchangeable, because the interchange will not alter the resulted ISR-N. Hence, an SCP problem is simplified into an SCFA-SCS problem whose computational complexity is much lower. The numerical results validated that our proposed algorithm outperforms the existing SCP algorithms in various circumstances.

APPENDIX. DERIVATION OF INTERFERENCE TO SIGNAL RATIO

The definition and formulation of ISR of a user $G_{s_p,s_q}(\eta_{p,q}^{x,y}, \tau_{p,q}^{x,y})$ are presented in this appendix. First, the SIR after signal filtering and de-spreading is formulated. Then, the worst SIR is derived. Finally, the ISR of the user is defined as the mean of the worst ISRs. In TD-SCDMA downlink, spreading factor $N=16$ is considered in Section III-A. Therefore, there are 16 spreading codes, offering 16 physical transmission channels in each cell.

First, assume that each user occupies one channel for the convenience of analysis. After signal filtering and de-spreading, the instantaneous SIR between interfered and interfering users is

$$\text{SIR} = \frac{\hat{\eta}}{\rho(\tau)},$$

(A.1)

where $\hat{\eta}$ is the instantaneous CIR between serving and interfering signals. According to [7], we get

$$\rho(\tau) \triangleq \sum_{i=-\infty}^{\infty} \rho_w(-iT - \tau) \rho_w^*(iT - \tau),$$

(A.2)

where $\tau$ is time delay, $T$ is symbol duration, $i$ is the index of data symbol, and $\rho_w(t)$ is the cross correlation between the waveforms of the interfered and interfering users. In TD-SCDMA we have

$$\rho_w(t) = \frac{1}{N} \sum_{\delta=1-N}^{N-1} r(\delta) \rho_p(t + \delta T_c),$$

(A.3)

where $T_c$ is the chip duration, $\rho_p(t) \triangleq \int_{-\infty}^{\infty} \xi(t + \tau) \xi(\tau) d\tau$ is the autocorrelation of the chip pulse shape $\xi(t)$, and $r(\delta)$ is the aperiodic correlation function defined in [7], which was formulated in Section III-A. It is worth noting that $r(\delta)$ is invariant in TD-SCDMA with $N=16$. 
For networking planning purpose, only the statistical results averaged over small-scale fading distributions are meaningful. The averaged SIR can be obtained through simply replacing the instantaneous CIR in Eq. (A.1) by the averaged CIR \( \eta \), which can be easily measured from a network.

Assume that the interfered user at location \((x, y)\) uses the \(a\)-th spreading code of the \(p\)-th cell. Further presume that the interfering user occupying the same time slot uses the \(b\)-th spreading code of the \(q\)-th cell, which has the highest cross correlation with the \(a\)-th spreading code of the \(p\)-th cell among all spreading codes of the \(q\)-th cell. Hence, the worst SIR of this user is

\[
SIR_{p,q}^{x,y} = \frac{\eta_{p,q}^{x,y}}{\max_{b=1,2,\ldots,16} \{ \rho_{p,q}(\tau_{p,q}) \}}.
\]  

(A.4)

The meaning of the worst case is three-fold: (1) interfered and interfering users occupy the same time slot; (2) their spreading codes have the highest cross correlation; and (3) all downlink signals are transmitted with the maximum power, so that interference is the strongest over the whole network.

Finally, assume that a user uses one of the 16 spreading codes at equal probability. Thus, we can define ISR of the user at \((x, y)\) in an average sense as

\[
G_{s_p,s_q}(\tau_{p,q}) = \frac{1}{16} \sum_{a=1}^{16} \frac{\max_{b=1,2,\ldots,16} \{ \rho_{p,q}(\tau_{p,q}) \}}{\eta_{p,q}^{x,y}}.
\]  

(A.5)

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REFERENCES


Fig. 1. Procedure of spreading modulation with complex codes.

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<td>$-j$</td>
<td>$j$</td>
<td>-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE I

**COMPLEXIFICATION FACTOR FOR TD-SCDMA CHANNELIZATION CODES.**
Fig. 2. ISR-Ns under different traffic density ratios.

Fig. 3. ISR-Ns under different minimum distance thresholds, where traffic density ratio is one.
TABLE II
SCRAMBLING CODE FAMILIES, THEIR SCRAMBLING CODES, AND THEIR ASSOCIATED CODE GROUPS.

<table>
<thead>
<tr>
<th>Scrambling code family ID</th>
<th>Scrambling code ID [3]</th>
<th>Code group ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 4 25 6 25 28 29 33 39 41 42 48 52 54 56 84 89</td>
<td>1 2 7 8 9 10 11 13 14 15 22 23</td>
</tr>
<tr>
<td>2</td>
<td>1 5 7 10 15 20 40 46 47 49 61 64 75 82 118 126</td>
<td>1 2 3 4 5 6 11 12 13 16 17 19 21 30 32</td>
</tr>
<tr>
<td>3</td>
<td>2 3 6 11 12 17 22 23 34 35 36 38 45 50 65 86</td>
<td>1 2 3 4 5 6 9 10 12 13 17 22</td>
</tr>
<tr>
<td>4</td>
<td>8 9 13 14 18 19 24 27 32 37 44 67 70 104 116 117</td>
<td>3 4 5 7 9 10 12 17 18 27 30</td>
</tr>
<tr>
<td>5</td>
<td>16 21 30 31 43 59 78 85 92 94 99 105 107 109 124 125</td>
<td>5 6 8 11 15 20 22 24 25 27 28 32</td>
</tr>
<tr>
<td>6</td>
<td>51 58 102 127</td>
<td>13 15 26 32</td>
</tr>
<tr>
<td>7</td>
<td>53 80 91 100 120</td>
<td>14 21 23 26 31</td>
</tr>
<tr>
<td>8</td>
<td>55 60 71 83 87 112 115</td>
<td>14 16 18 21 22 29</td>
</tr>
<tr>
<td>9</td>
<td>57 77 81 88 96 97 101</td>
<td>15 20 21 23 25 26</td>
</tr>
<tr>
<td>10</td>
<td>62 68 69 76 108 122</td>
<td>16 18 20 28 31</td>
</tr>
<tr>
<td>11</td>
<td>63 66 72 79 93 95 106 110 113 123</td>
<td>16 17 19 20 24 27 28 29 31</td>
</tr>
<tr>
<td>12</td>
<td>73 74 90 98 103 114 119 121</td>
<td>19 23 25 26 28 29 30 31</td>
</tr>
</tbody>
</table>

TABLE III
PARAMETER SETTINGS.

<table>
<thead>
<tr>
<th>Network scenario</th>
<th>Network coverage</th>
<th>15.5⇥18.2 km²</th>
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</thead>
<tbody>
<tr>
<td>Number of cells</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Uniform hexagonal layouts</td>
<td>Radius of hexagon is 1000 m, and BSs are located roughly at the hexagon center with a fluctuation obeying $N(0, 400)$.</td>
<td></td>
</tr>
<tr>
<td>Irregular layouts</td>
<td>BSs are randomly deployed with the distance between any two BSs being longer than a minimum distance threshold.</td>
<td></td>
</tr>
<tr>
<td>User distribution</td>
<td>Users are located at the vertex of uniform lattices, whose size is 100⇥100 m².</td>
<td></td>
</tr>
<tr>
<td>Traffic distribution</td>
<td>25 randomly chosen cells are heavy traffic cells and the others are normal traffic cells.</td>
<td></td>
</tr>
<tr>
<td>BS transmission power</td>
<td>25 dBm</td>
<td></td>
</tr>
<tr>
<td>Propagation model</td>
<td>Wideband PCS microcell model [12]</td>
<td></td>
</tr>
<tr>
<td>CIR intervals (in dB)</td>
<td>$(-\infty, -12], (-12, -9], \cdots, (9, 12], (12, \infty)$</td>
<td></td>
</tr>
<tr>
<td>Delay intervals (in chip)</td>
<td>$(-\infty, -15], (-15, -14], \cdots, (14, 15], (15, \infty)$</td>
<td></td>
</tr>
<tr>
<td>Clique algorithm</td>
<td>Tolerable cross correlation</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Maximum delay</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Interference metric threshold</td>
<td>16</td>
</tr>
</tbody>
</table>
Dear Editors and Anonymous Reviewers:

Thank you for your decision letter (dated May 3, 2013) with yours invaluable comments on our manuscript entitled "Scrambling Code Planning in TD-SCDMA Cellular Systems", which was submitted to IEEE Transactions on Vehicular Technology for possible publication. We have carefully addressed all of your suggestions and concerns, and revised our manuscript accordingly. Our responses to the reviewers’ comments are attached in this revision summary report.

We would like to thank you for the efforts in handling our paper, and we are grateful to all the reviewers for their thoughtful and constructive comments.

RESPONSE TO REVIEWER 1

Reviewer’s Comment:
1) Page 16, TABLE III, it is recommended that the units of "CIR intervals" and also "Delay intervals" should be indicated.

Authors’ Response:
Thank you for your comments, we have added the units accordingly in the revised manuscript.

RESPONSE TO REVIEWER 2

Reviewer’s Comment:
The reviewer has no further comments.

Authors’ Response:
Thank you for your effort in reviewing this manuscript.