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A novel cell search scheme for OFDM cellular systems*

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Abstract: A novel cell search scheme for OFDM cellular systems is proposed. It is based on one OFDM symbol with several identical slots as preamble, the time domain repetition structure of which can be utilized to accomplish OFDM timing/frequency synchronization. The cell ID is comprised of two parts: a sub-carrier mask index g and a sequence index x. Each sub-carrier mask activates or deactivates some of the sub-carriers, after which a differentially coded sequence is loaded on pairs of the adjacent active sub-carriers. The user equipment (UE) recognizes the mask with index g via power detection of the received frequency domain signal. Then it estimates the index x from differential demodulation followed by detection of the frequency domain sequence. In order to improve the performance, a method of jointly estimating g and x is devised. Simulation results showed that the proposed scheme is able to support a very large number of cell IDs while maintaining a good performance even in bad multi-cell environment.

Key words: Orthogonal frequency division multiplexing (OFDM), Cell search, Cell ID, Multi-cell, Mask
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INTRODUCTION

Owing to its inherent ability to combat the multi-path fading channel, the modulation technology of orthogonal frequency division multiplexing (OFDM) has been widely used in many high-rate data transmissions such as digital video broadcasting (DVB-T), wireless local area network (IEEE 802.11a) and broadband wireless access (IEEE 802.16e). Recently, it is accepted as the most promising candidate for E-UTRA downlink (3GPP TSG-RAN-1, 2006a), which is a super 3G cellular system. Before the user equipment (UE) makes a cell access, it needs to perform a quick cell search, including initial timing/ frequency synchronization and cell ID identification. The issue of OFDM timing/frequency synchronization has been studied extensively. However, most of the research results cannot be applied to multi-cell environment since the scheme of discriminating signals from adjacent cells is not available.

Kim *et al.*(2005) proposed a method, in which a preamble composed of one OFDM symbol with L identical slots is used. This type of preamble is generated by transmitting data on the frequency grids multiple of L and setting zeros on the remaining frequencies, resulting in a comb-shaped spectrum. The sub-carriers corresponding to the comb fingers are called active sub-carriers and the others are called null sub-carriers. A cell-specific PN sequence is loaded on the active sub-carriers. After performing OFDM synchronization by exploiting the time domain repetition structure of the preamble, the UE estimates the cell ID from peak detection of the cross-correlation between the received signal and the known PN sequences. However, Kim's method is very sensitive to the performance of channel estimation since multi-path fading channel could severely corrupt the received sequence. To alleviate this problem, another approach based on generating the PN sequence in a differentially coded manner is proposed (Kwon *et al.*, 2004; Lee and Lee, 2005), thus, the UE can employ differential demodulation of pairs of adjacent sub-carriers to eliminate the channel corruption. An-

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other method uses other kind of differentially coded sequence (3GPP TSG-RAN-1, 2005), the phase difference of which increases proportionally to cell ID. As a result, the UE detects its cell ID through an IFFT-based peak searching instead of correlations over multiple candidate sequences, which saves a lot of computational complexity. In this paper, we refer to this scheme as Method A. Although Method A seems to be quite satisfying, it is not capable of supporting a very large number of unique cell IDs since the length of the differentially coded sequence is usually limited. Assigning several OFDM symbols as preamble to extend the sequence length may solve the problem (3GPP TSG-RAN-1, 2006b), at the price of decreased transmission efficiency.

In this paper, we propose a low overhead oriented cell search scheme for OFDM cellular systems, which uses only one OFDM symbol with the L-repetition structure. This type of structure makes it easy to accomplish OFDM timing/frequency synchronization. The cell ID is comprised of two parts: a sub-carrier mask index g and a sequence index x. Each sub-carrier mask is a cyclic shifted binary sequence with a unique index g, which acts like a switch array to control the state of a subset of the active sub-carriers. Every ‘0’ in the mask means turning the corresponding active sub-carrier into a null sub-carrier with ‘1’ changing nothing. The UE recognizes the sub-carrier mask via power detection of the received signal in frequency domain. Furthermore, a differentially coded sequence indexed x like Method A is loaded on the pairs of adjacent active sub-carriers. Therefore, the same algorithm as Method A can be used for sequence index identification. Computer simulations showed that our scheme is capable of supporting a very large number of cell IDs while maintaining a good performance even in bad multi-cell environment.

Notation: superscript * stands for conjugation. $\{\cdot\}_z$ denotes the modulo-z operation. $E(Y)$ denotes the number of elements in set Y. $\lfloor x \rfloor$ denotes the maximal integer not exceeding x and $MinP(x)$ denotes the minimum prime number exceeding x.

SYSTEM MODEL

OFDM is a multi-carrier modulation system, where each usable sub-carrier is loaded with a QAM or PSK signal $\{a(k)\}$, where k denotes the sub-carrier index. The time-domain complex baseband samples $\{b(l)\}$ of an OFDM symbol with N sub-carriers are generated by taking the N-point IDFT as

$$b(l)=\frac{1}{\sqrt{N}}\sum_{k=-N_{u2}}^{N_{u1}} a(k)\exp\left(\mathrm{j}\frac{2\pi kl}{N}\right),\ -N_g\le l\le N-1, \quad (1)$$

where the number of used sub-carriers is $N_{u1}+N_{u2}+1=N_u\le N$. The useful part of each OFDM symbol has duration of T corresponding to N samples. N_g is the length of cyclic prefix (CP). The resulting symbol is transmitted through the frequency-selective channel, whose finite impulse response is $h(l)$.

Assuming that perfect timing/frequency synchronization has been achieved, the received complex base-band signal is sampled with period $T_s=T/N$ and can be expressed as

$$r(m)=\exp(\mathrm{j}\psi)\sum_{l} b(m-l)h(l)+n(m), \quad (2)$$

where ψ is an arbitrary phase factor, $n(m)$ is the sample of complex Gaussian noise with variance σ_n^2 in time domain.

Taking the N-point DFT after discarding the CP of N_g samples from $r(m)$, the received frequency domain signal can be presented as

$$z(k)=\frac{1}{\sqrt{N}}\sum_{m=0}^{N-1} r(m)\exp\left(-\mathrm{j}\frac{2\pi mk}{N}\right)=a(k)H(k)+\overline{n}(k),$$
$$-N_{u1}\le k\le N_{u2}, \quad (3)$$

where $H(k)$ is the frequency response of the channel and $\overline{n}(k)$ denotes the noise in frequency domain.

PROPOSED CELL SEARCH SCHEME

Preamble designing

In this paper, we design a new preamble, consisting of only one OFDM symbol with L identical slots. In frequency domain, we introduce the sub-carrier mask, which is a binary sequence denoted as $\boldsymbol{d}^g=\{d^g(i)\}$ with a mask index of g. The mask controls the state of a subset of the active sub-carriers.

Every ‘0’ in the mask means turning the corresponding active sub-carrier into a null sub-carrier and ‘1’ changing nothing. To clearly describe the design of our preamble, we define several sub-carrier sets as follows.

Firstly, S denotes the set of the original active sub-carriers before the process of masking:

$$S=\left\{ s(i) \,\middle|\, \begin{array}{l} 1\le i\le E(S), s(i)<s(i+1), s(i)\ne 0 \\ -N_{\mathrm{u1}}\le s(i)\le N_{\mathrm{u2}} \text{ and } \{s(i)\}_L=0 \end{array} \right\}. \quad (4)$$

It is readily obtained that the number of elements in S is $E(S)=\lfloor N_{\mathrm{u1}}/L\rfloor+\lfloor N_{\mathrm{u2}}/L\rfloor$.

Secondly, S_{mask} represents the subset of S controlled by the sub-carrier mask:

$$S_{\mathrm{mask}}=\left\{ s_{\mathrm{m}}(i) \,\middle|\, \begin{array}{l} 1\le i\le E(S_{\mathrm{mask}}), s_{\mathrm{m}}(i)<s_{\mathrm{m}}(i+1) \\ s_{\mathrm{m}}(i)\in S \end{array} \right\}. \quad (5)$$

Let the mask length be B and, thus, the elements in S_{mask} is $E(S_{\mathrm{mask}})=B$. Later we will see that the mask should be a binary sequence enjoying low auto-correlation property, which places some restrictions on B.

Thirdly, denote the subset of S that will never be affected by all $\boldsymbol{d}^g$ as S_{load}:

$$S_{\mathrm{load}}=\left\{ s_{\mathrm{l}}(i) \,\middle|\, \begin{array}{l} 1\le i\le E(S_{\mathrm{load}}), s_{\mathrm{l}}(i)<s_{\mathrm{l}}(i+1) \\ s_{\mathrm{l}}(i)\in S\setminus S_{\mathrm{mask}} \end{array} \right\}. \quad (6)$$

Obviously, $E(S_{\mathrm{load}})=E(S)-E(S_{\mathrm{mask}})$. A simple way to design S_{load} is allocating $E(S_{\mathrm{load}})$ adjacent sub-carriers to it.

As mentioned above, after S_{mask} is masked by $\boldsymbol{d}^g$, some $s_{\mathrm{m}}(i)$ will be deactivated when $d^g(i)=0$, which constitute the deactivated sub-carrier set S_{deact}^g:

$$S_{\mathrm{deact}}^g=\{s_{\mathrm{m}}(i)|\text{ when } d^g(i)=0,\ 1\le i\le E(S_{\mathrm{mask}})\}. \quad (7)$$

The others constitute the surviving sub-carrier set S_{surv}^g:

$$S_{\mathrm{surv}}^g=\left\{ s_{\mathrm{s}}^g(i) \,\middle|\, \begin{array}{l} 1\le i\le E(S_{\mathrm{surv}}^g), s_{\mathrm{s}}^g(i)<s_{\mathrm{s}}^g(i+1) \\ s_{\mathrm{s}}^g(i)\in S_{\mathrm{mask}}\setminus S_{\mathrm{deact}}^g \end{array} \right\}. \quad (8)$$

In Eq.(8), let $E(S_{\mathrm{surv}}^g)=A$, where A is the number of ‘1’ in $\boldsymbol{d}^g$. Therefore, S_{load} combined with S_{surv}^g are the active sub-carriers of our preamble expressed as

$$S_{\mathrm{act}}^g=\left\{ s_{\mathrm{a}}^g(i) \,\middle|\, \begin{array}{l} 1\le i\le E(S_{\mathrm{act}}^g), s_{\mathrm{a}}^g(i)<s_{\mathrm{a}}^g(i+1) \\ s_{\mathrm{a}}^g(i)\in S_{\mathrm{load}}\cup S_{\mathrm{surv}}^g \end{array} \right\}. \quad (9)$$

Considering $S_{\mathrm{load}}\cap S_{\mathrm{surv}}^g=\varnothing$, we get $E(S_{\mathrm{act}}^g)=E(S_{\mathrm{load}})+E(S_{\mathrm{surv}}^g)=E(S_{\mathrm{load}})+A$.

The relations among S, S_{mask}, S_{load}, S_{surv}^g and S_{act}^g are illustrated in Fig.1.

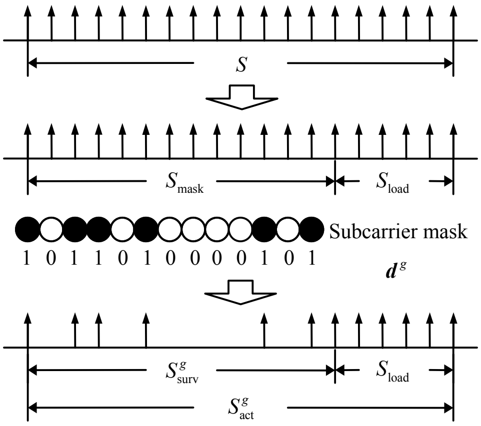

Fig.1 Relations among different subcarrier sets

Mask $\boldsymbol{d}^g$ can be recognized by power detection of signals on sub-carriers belonging to S_{mask} at the UE. It is preferred that the Hamming distances among the masks should be made as large as possible. Moreover, the parameter A should be the same for all $\boldsymbol{d}^g$ to ensure that all cells generate the preamble with the same energy boosting level on sub-carriers belonging to S_{act}^g. To satisfy these two goals, we choose a binary sequence, which enjoys low auto-correlation property, together with its cyclic shift versions to construct the mask bank $\boldsymbol{d}^g$ ($1\le g\le B$).

For example, the m-sequence is a perfect candidate for $\boldsymbol{d}^g$, the length of which is $B=2^{\alpha}-1$ (α is a natural number), leading to totally B unique masks.

While in a particular cell with mask $\boldsymbol{d}^g$, it loads differentially coded sequence like Method A on the pairs of adjacent active sub-carriers represented by $(s_{\mathrm{a1}}^g(i), s_{\mathrm{a2}}^g(i))$, which belong to S_{adj}^g:

$$S_{\text{adj}}^{g}=\left\{\begin{pmatrix}s_{\text{a1}}^{g}(i),\\ s_{\text{a2}}^{g}(i)\end{pmatrix}\left|\begin{array}{l}1\le i\le E(S_{\text{adj}}^{g}),\\ s_{\text{a1}}^{g}(i)<s_{\text{a1}}^{g}(i+1),s_{\text{a2}}^{g}(i)<s_{\text{a2}}^{g}(i+1)\\ \text{when } s_{\text{a1}}^{g}(i)\in S_{\text{act}}^{g},\ s_{\text{a2}}^{g}(i)\in S_{\text{act}}^{g}\\ \text{and } 0<s_{\text{a2}}^{g}(i)-s_{\text{a1}}^{g}(i)\le\lambda\end{array}\right.\right\},\tag{10}$$

where λ is the defined maximum distance between adjacent sub-carriers. Usually, λ=2~4 to ensure that sub-carrier pairs corresponding to $s_{\text{a1}}^{g}(i)$ and $s_{\text{a2}}^{g}(i)$ nearly experience the same channel fading.

In Eq.(10), $E(S_{\text{adj}}^{g})$ varies with g, implying that cells with different $\boldsymbol{d}^g$ may have a different length of differentially coded sequence, which is quite undesirable. In our scheme, we truncate all S_{adj}^{g} to the same length C:

$$C=\min\{E(S_{\text{adj}}^{g})|1\le g\le B\}.\tag{11}$$

Then, substituting $E(S_{\text{adj}}^{g})$ with C in Eq.(10) yields

$$S_{\text{adj}}^{g}=\left\{\begin{pmatrix}s_{\text{a1}}^{g}(i),\\ s_{\text{a2}}^{g}(i)\end{pmatrix}\left|\begin{array}{l}1\le i\le C,\\ s_{\text{a1}}^{g}(i)<s_{\text{a1}}^{g}(i+1),s_{\text{a2}}^{g}(i)<s_{\text{a2}}^{g}(i+1)\\ \text{when } s_{\text{a1}}^{g}(i)\in S_{\text{act}}^{g},\ s_{\text{a2}}^{g}(i)\in S_{\text{act}}^{g}\\ \text{and } 0<s_{\text{a2}}^{g}(i)-s_{\text{a1}}^{g}(i)\le\lambda\end{array}\right.\right\}.\tag{12}$$

From Fig.1, we notice that the elements of S_{surv}^{g} appear to scatter irregularly in frequency domain, thus, the pairs of adjacent active sub-carriers also distribute unevenly, which introduces some kind of randomly distributed frequency diversity. However, the number of adjacent sub-carrier pairs decreases dramatically since many sub-carriers may be deactivated by $\boldsymbol{d}^g$ and the distance of adjacent sub-carriers must be smaller than λ. That is another factor why we allocate some sub-carriers to S_{load}, which is always powered on to make sure that there are enough adjacent sub-carrier pairs that can be used to load differentially coded sequence. The larger the C is, the more distinct sequences there will be.

Following Eqs.(9) and (12), the multiplexing of the differentially coded sequence on S_{act}^{g} can be expressed as

$$a(s_{\text{a}}^{g}(j))=\begin{cases}a(s_{\text{a1}}^{g}(i))p^{x}(i), & \exists s_{\text{a2}}^{g}(i),\ s_{\text{a}}^{g}(j)=s_{\text{a2}}^{g}(i),\\ \exp(\text{j}\theta), & \forall s_{\text{a2}}^{g}(i),\ s_{\text{a}}^{g}(j)\ne s_{\text{a2}}^{g}(i),\end{cases}\tag{13}$$
$$1\le i\le C;\ 1\le j\le E(S_{\text{act}}^{g}),$$

where θ is a random phase, which helps to reduce the peak-to-average power ratio (PAPR) of the preamble signal. And the sequence $\boldsymbol{p}^x$={$p^x(i)$} is differentially coded from a GCL sequence like that of Method A (3GPP TSG-RAN-1, 2005), which is represented as

$$v_{\text{GCL}}^{x}(i)=\exp\left(-\text{j}2\pi x\frac{i(i+1)}{2MinP(C)}\right),\tag{14}$$
$$0\le i\le MinP(C);\ 1\le x\le MinP(C)-1.$$

Obtain $p^x(i)$ from differential computation of $v_{\text{GCL}}^{x}(i)$:

$$p^{x}(i)=(v_{\text{GCL}}^{x}(i-1))^{*}v_{\text{GCL}}^{x}(i)=\exp\left(-\text{j}2\pi x\frac{i}{MinP(C)}\right),$$
$$1\le i\le MinP(C);1\le x\le MinP(C)-1.\tag{15}$$

Totally $MinP(C)-1$ different sequences are available. Therefore, our two-step cell ID identification scheme can distinguish $B(MinP(C)-1)$ unique cells, while that of Method A is merely $MinP(E(S))-1$. In the section of simulations and discussions, we will implement our scheme on a system with N=128, N_{u}=76, L=2, B=31, λ=4, C=17 and $E(S)$=37. Thereby, Method A can only identify $MinP(E(S))-1$=36 unique cells. But our scheme is able to support $B(MinP(C)-1)$=496 cells, the number of which is nearly 14 times that of Method A.

Cell search procedure

For a cell with mask index G and sequence index X, sub-carriers belonging to S_{mask} will be masked by $\boldsymbol{d}^G$ and loaded with differentially coded sequence $\boldsymbol{p}^X$, which maintains the L-repetition structure for OFDM synchronization. Assuming that OFDM timing/frequency synchronization has been perfectly achieved, we focus our discussions on the issue of cell ID identification.

Performing power detection of the received signal on sub-carriers belonging to S_{mask} and cross-correlation with all possible $\boldsymbol{d}^g$, we get

$$R(g)=\sum_{i=1}^{B}\left|z(S_{\mathrm{m}}(i))\right|^{2}d^{g}(i),\ 1\le g\le B. \tag{16}$$

The cell mask index is estimated through peak detection:

$$\hat{g}=\arg\max_{g}\left\{R(g)\,\middle|\,1\le g\le B\right\}. \tag{17}$$

Considering a successful mask identification has been achieved ($\hat{g}$=G), S_{act}^{G} and S_{adj}^{G} can be deduced from Eqs.(9) and (12) respectively. Employing differential demodulation of sub-carrier pairs belonging to S_{adj}^{g}, we get $q(i)$ in the absence of noise:

$$\begin{aligned}q(i)=z(s_{\mathrm{a1}}^{G}(i))^{*}\,z(s_{\mathrm{a2}}^{G}(i))=[a(s_{\mathrm{a1}}^{G}(i))H(s_{\mathrm{a1}}^{G}(i))]^{*}\cdot\\ [a(s_{\mathrm{a2}}^{G}(i))H(s_{\mathrm{a2}}^{G}(i))],\qquad 1\le i\le C.\end{aligned} \tag{18}$$

Since λ is small enough to make $H(s_{\mathrm{a2}}^{G}(i))\approx H(s_{\mathrm{a1}}^{G}(i))$, Eq.(18) can be written as

$$q(i)\approx a(s_{\mathrm{a1}}^{G}(i))^{*}\,a(s_{\mathrm{a2}}^{G}(i))|H(s_{\mathrm{a1}}^{G}(i))|^{2}=p^{X}(i)|H(s_{\mathrm{a1}}^{G}(i))|^{2}. \tag{19}$$

Taking the cross-correlation between $\boldsymbol{q}$={$q(i)$} and all possible $\boldsymbol{p}^{x}$, we have

$$T(x)=\left|\sum_{i=1}^{C}q^{*}(i)p^{x}(i)\right|^{2},\ 1\le x\le MinP(C)-1. \tag{20}$$

Then we estimate the sequence index from peak searching:

$$\hat{x}=\arg\max_{x}\{T(x)\,|\,1\le x\le MinP(C)-1\}. \tag{21}$$

Like Method A, Eq.(20) can be implemented efficiently through $MinP(C)$-point IFFT algorithm (Selesnick and Burrus, 1996) instead of correlations over multiple candidate sequences, which reduces computational complexity considerably.

To enhance the estimation performance, we can simply observe several preambles and accumulate $R(g)$ and $T(x)$ to more reliable values before executing Eqs.(17) and (21).

$$R(g)=\sum_{j=1}^{M}R_{j}(g),\ 1\le g\le B, \tag{22}$$

$$T(x)=\sum_{j=1}^{M}T_{j}(x),\ 1\le x\le MinP(C)-1, \tag{23}$$

where M is the number of observed preambles, $R_j(g)$ and $T_j(x)$ are obtained from Eqs.(16) and (20) respectively for the jth preamble.

Joint estimation of mask index and sequence index

Note that in Eqs.(17) and (21), the estimation of mask index g and sequence index x is performed separately and serially, thus, we need to estimate g and x both correctly to declare a successful cell ID identification, which severely degrade the performance of our scheme. Therefore, we devise a joint estimation method to alleviate this problem.

According to Eq.(12), different masks result in different patterns of adjacent sub-carrier pairs. If Eq.(17) makes a wrong estimation ($\hat{g}\neq G$), $T(x)$ in Eq.(20) will fail to exhibit a sharp peak since $q(i)$ is differentially demodulated from the wrong positions of adjacent active sub-carrier pairs. Thus, it is more appropriate to reach an estimation result $(\hat{g},\hat{x})$ when $R(\hat{g})$ and $T(\hat{x})$ are jointly maximized. Define a joint decision metric as

$$W(g,x)=R(g)T^{g}(x), \tag{24}$$

where $R(g)$ is the same as that in Eq.(16), $T^{g}(x)$ is calculated from Eq.(20) under the condition of $\boldsymbol{d}^{g}$:

$$T^{g}(x)=\left|\sum_{i=1}^{C}(q^{g}(i))^{*}p^{x}(i)\right|^{2}, \tag{25}$$

where $q^{g}(i)=z^{*}(s_{\mathrm{a2}}^{g}(i))z(s_{\mathrm{a1}}^{g}(i))$. Finally, g and x are jointly estimated from

$$\begin{aligned}(\hat{g},\hat{x})=\arg\max_{(g,x)}\{W(g,x)\,|\,1\le g\le B,\\ 1\le x\le MinP(C)-1\}.\end{aligned} \tag{26}$$

Also, Eq.(26) can be performed after observing M preambles. In this case, $W(g,x)$ is expressed as

$$W(g,x)=\sum_{j=1}^{M}R_{j}(g)T_{j}^{g}(x), \tag{27}$$

where M is the number of observed preambles, $R_j(g)$

and $T_j^g(x)$ are obtained from Eqs.(16) and (25) respectively for the *j*th preamble.

In the following part of this paper, we refer to the estimation scheme from Eqs.(17) and (21) as Scheme I, while the joint estimation method from Eq.(26) is called Scheme II.

Complexity comparison and improvement of joint estimation algorithm

Apart from the computations for synchronization and the FFT of the preamble, the main computational load of Method A is $E(S)-1$ complex multiplications for differential modulation (similar to Eq.(18)) and a $MinP(E(S))$-point IFFT for sequence detection (similar to Eq.(20)), while that of Scheme I is B complex multiplications for Eq.(16), C complex multiplications for Eq.(18) and a $MinP(C)$-point IFFT for Eq.(20). On the whole, the complexity of Scheme I is approximately the same as that of Method A. However, Scheme II necessitates much more computation than Scheme I since each g calls for a differential demodulation process and a $MinP(C)$-point IFFT in Eq.(25). In order to reduce its complexity, we sort $R(g)$ from Eq.(16) in descending order and select the top η ($1\le\eta\le B$) candidates. Denote the indices g of the candidates belong to the set $G_{\rm sel}(\eta)$. Then, we modify Eq.(25) as

$$T^g(x)=\begin{cases}0, & g\notin G_{\rm sel}(\eta),\\ \left|\sum_{i=1}^{C}(q^g(i))^* p^x(i)\right|^2, & g\in G_{\rm sel}(\eta).\end{cases} \qquad (28)$$

Therefore, the complexity of Scheme II will approximately decrease to η/B of that of the original one. However, a relatively small η will certainly introduce some performance degradation. We should make an appropriate trade-off when designing a practical system.

SIMULATION RESULTS AND DISCUSSION

Simulations were conducted to test the performance of the proposed cell search scheme. The simulation parameters are set according to 3GPP (3GPP TSG-RAN-1, 2006a). The entire channel bandwidth is 1.92 MHz and is divided into N=128 sub-carriers, while the number of used sub-carriers is $N_{\rm u}$=76. A cyclic prefix with length of $N_{\rm g}$=32 samples is used to provide protection from ISI. Moreover, we set L=2, thus, $S=\{s(i)=-38, -36, \ldots, -2, 2, \ldots, 34, 36\}$ and $E(S)$=37. Choosing α=5, thereby, $B=2^{\alpha}-1=31$. Then we designate $S_{\rm mask}=\{s_{\rm m}(i)=-38, -36, \ldots, -8, 8, \ldots, 34, 36\}$ and $S_{\rm load}=\{s_{\rm l}(i)=-6, -4, -2, 2, 4, 6\}$, leading to $E(S_{\rm mask})=B=31$ and $E(S_{\rm load})=6$. Each $\boldsymbol{d}^g$ is the cyclic shift version of an *m*-sequence: 05763E69 (in hexadecimal), the length of which is 31. Considering the basic characteristics of *m*-sequence, the minimum Hamming distance among the masks is 16 and $A=(B+1)/2=16$, thus, $E(S_{\rm act}^g)=E(S_{\rm load})+A=6+16=22$. Setting λ=4 and analyzing all possible $S_{\rm adj}^g$ from Eq.(10), we get C=17 according to Eq.(11). Therefore, our scheme can totally identify $B(MinP(C)-1)$=496 unique cells. However, Method A can only identify $MinP(E(S))-1$=36 different cells, the number of which is about 1/14 of that of our method.

In multi-cell environment, each cell generates its own preamble according to Eq.(1), where $\{a(k)\}$ comes from Eq.(13). Considering a situation with heavy interference, the preambles from three adjacent cells with three distinct combinations of g and x (randomly selected from all possible (g, x)) arrive at the UE simultaneously. Among the three preamble signals, one preamble having a strongest power represents the best cell. The other two have identical power levels and can be regarded as interference. Each preamble signal is transmitted through its distinct Rayleigh fading channel, which is modelled as GSM TU (6 rays, 3 km/h).

Under the condition that perfect OFDM timing/frequency synchronization has been accomplished, Fig.2a and Fig.2b give the cell ID detection probability performance of Scheme I vs Method A and Scheme II vs Method A respectively in the presence of different SIRs, which is defined as the power from the best cell over the sum of that of the other two cells. Furthermore, the power of the background Gaussian noise is 0 dB compared to that of the best cell. To achieve a relatively satisfactory performance, both schemes make cell ID estimation after observing M (M=1, 3, 5) preambles.

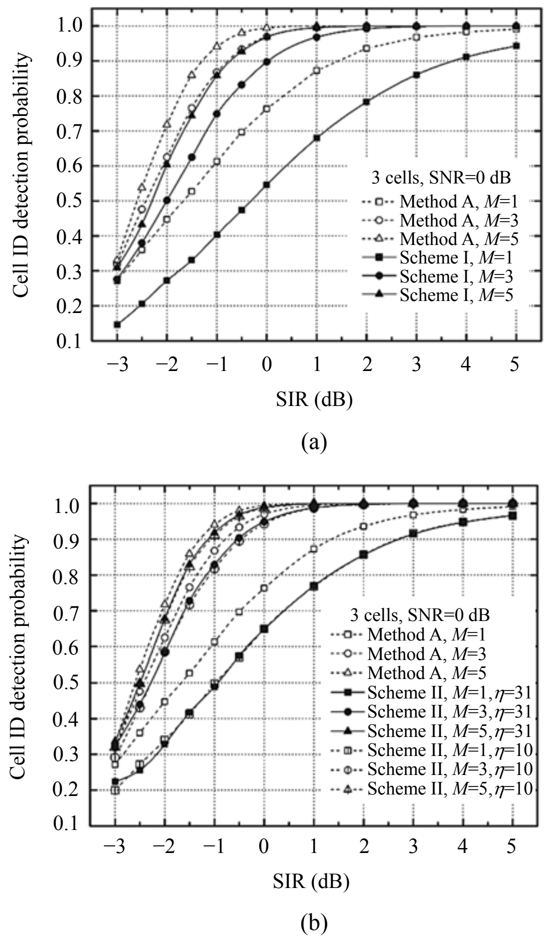

Fig.2 Cell ID detection probability in the scenario of 3 cells. (a) Scheme I vs Method A; (b) Scheme II vs Method A

It shows that when M=1, Scheme I and Scheme II (both η=31 and η=10) are inferior to Method A by about 2 dB and 1.2 dB respectively. However, as M increases (M=5), the performance gap between Scheme II (both η=31 and η=10) and Method A is only 0.1 dB, while Scheme I substantially narrows the performance gap from 2 dB (M=1) to 0.7 dB (M=5). It should also be noted that the complexity of Scheme II with η=10 is only about 33% of that with η=31, yet they exhibit almost the same performance. Thus, the improved joint estimation algorithm is very effective.

Furthermore, Fig.3 presents the performance comparisons when the interference is modelled as Gaussian noise. And the interference and noise are measured by SINR. The performance gap between Scheme I and Method A is approximately 2 dB (M=1) and 0.8 dB (M=5), while that between Scheme II (η=31) and Method A is 1.3 dB (M=1) and trivially 0.2 dB (M=5). In this scenario, when M>3, Scheme II with η=10 is 0.1~0.2 dB inferior to that with η=31. Considering it slashes the computational complexity by approximately 67%, this slight performance degradation is acceptable.

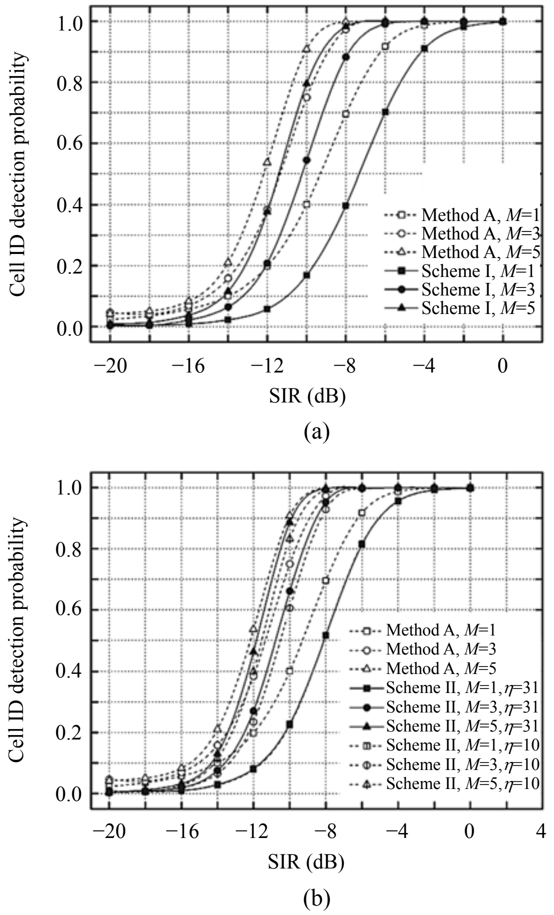

Fig.3 Cell ID detection probability in the scenario of Gaussian interference and noise. (a) Scheme I vs Method A; (b) Scheme II vs Method A

Therefore, the proposed joint estimation scheme significantly improves the cell search performance compared with the non-joint estimation scheme. When M>3, the performance of Scheme II and Method A converge in both scenarios, while scheme II is able to support nearly 14 times the cell IDs as Method A.

CONCLUSION

In this paper we propose a cell search scheme for OFDM cellular systems, which uses only one OFDM symbol as preamble. The UE identifies its cell ID by a two-step estimation: mask index identification and sequence index identification. In order to improve the performance, a method of jointly estimating the two indices is devised. Simulation results showed that the proposed scheme can be used in an OFDM cellular system with a very large number of cell IDs and it works well even in bad multi-cell environment.

References

3GPP TSG-RAN-1, 2005. R1-051329 Cell Search and Initial Acquisition for OFDM Downlink. Http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_43/Docs/R1-051329.zip

3GPP TSG-RAN-1, 2006a. TR 25.814 Physical Layer Aspects for Evolved UTRA (Release 7). Http://www.3gpp.org/ftp/Specs/achive/25_series/25.814/25814-122.zip

3GPP TSG-RAN-1, 2006b. R1-060379 Cell Search and Initial Acquisition for EUTRA. Http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_44/Docs/R1-060379.zip

Kim, J., Kim, H., Han, Y., 2005. New Preamble Structures for Synchronization and Cell Searching in OFDM Systems. IEEE VTC'05 Fall. Dallas, TX, p.1623-1627.

Kwon, D.S., Lim, H., Park, H., 2004. Preamble structure for single frequency cellular systems using orthogonal frequency division multiplexing. *IEEE Transactions on Consumer Electronics*, **50**(1):115-118. [doi:10.1109/TCE.2004.1277849]

Lee, J., Lee, Y., 2005. Rapid Cell Search in OFDM-based Cellular Systems. IEEE VTC'05 Spring. Stockholm, Sweden, p.1273-1277.

Selesnick, I.W., Burrus, C.S., 1996. Automatic generation of prime length FFT programs. *IEEE Transactions on Signal Processing*, **44**(1):14-24. [doi:10.1109/78.482008]