A Novel Time Domain Synchronous Orthogonal Frequency Division Multiple Access Scheme

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***Abstract*—Time-domain synchronous orthogonal frequency division multiplexing (TDS-OFDM) outperforms cyclic prefixed-OFDM (CP-OFDM) in spectrum efficiency at the expense of higher complexity. Up to now, TDS-OFDM has only been used in unidirectional transmission, such as broadcasting applications. The overwhelming complexity of removing the implicitly superposed interferences between the PN sequences and IDFT information blocks, caused by multiple users, hinders the application of time-domain synchronous orthogonal frequency division multiple access (TDS-OFDMA) in multi-user communication scenarios. To solve this problem, this paper proposes a novel TDS-OFDMA scheme, including joint cyclicity reconstruction and joint channel estimation, utilizing the new "time-space two-dimensional frame structure". Theoretical analysis and computer simulation show that the proposed scheme not only can achieve the purpose of multiple access but also has an even better system performance in mobile environment than the conventional single-user TDS-OFDM system.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has been widely adopted in commercial systems such as terrestrial digital video broadcasting (DVB-T) [1] and the IEEE 802.11a wireless local area network (WLAN) [2]. Recently, there is a strong interest in extending the OFDM concept to multi-user communication scenarios. For access scheme, TDMA/FDMA/CDMA systems are proposed, yet the orthogonal frequency division multiple access (OFDMA) technology has not been adopted widely. OFDMA was originally suggested by Sari and Karam for cable TV (CATV) networks [3] and later adopted in the uplink of the interaction channel for digital terrestrial television (DVB-RCT) [4]. More recently, it has become part of the emerging IEEE 802.16 standards for wireless metropolitan area networks (WMANs) [5] and is currently attracting vast research attention from both academia and industry as a promising candidate for next generation broadband wireless networks [6].

In most OFDMA systems, cyclic prefix-OFDM (CP-OFDM) is used. It uses a sufficiently long cyclic prefix (CP) as the guard interval (GI) to combat inter-carrier interference (ICI) as well as to simplify channel equalization in the frequency domain with very low complexity [7]. However, it needs a large amount of extra training symbols or pilots in order to facilitate the synchronization and channel estimation (CE) [8], which decreases the spectral efficiency of this system.

Time domain synchronous-OFDM (TDS-OFDM) is the essential technology of the Chinese national digital television terrestrial broadcasting (DTTB) standard [9], which inserts pseudo-noise (PN) sequence instead of CP as the GI before the inverse discrete Fourier transform (IDFT) block. The PN sequences are also used for synchronization and CE [10]. Therefore, its spectral efficiency increases a lot. It has also been demonstrated that TDS-OFDM can provide even better performance than CP-OFDM [11]. However, the cyclicity of the received IDFT block is destroyed, since the PN sequence and the IDFT block will cause the inter-symbol interference (ISI) to each other. Therefore, iterative interference subtraction method [12] is adopted to remove the ISI between them and then reconstruct the cyclicity of the received IDFT block for CE and equalization. Based on this algorithm, other improving methods are proposed to increase the accuracy and convergence speed [13] [14].

When TDS-OFDM is applied to multiple access scenarios, we focus on TDS-OFDMA, since Rohling [15] has demonstrated that OFDMA clearly outperforms other multiple access techniques like OFDM-TDMA or OFDM-CDMA. However, the high complexity and dissatisfactory performance of those methods [12]-[14] make the interference cancellation in TDS-OFDMA systems almost impossible, since the superposed interferences caused by multiple users are much more complicated. Therefore, there is no literature addressing TDS-OFDMA system.

Aiming at the problem mentioned above, we propose a novel TDS-OFDMA scheme to cope with the implicitly combined interferences. Taking advantage of the new two-dimensional frame structure in the proposed system, not only the joint cyclicity reconstruction for all users is completed via one-step add-subtract operation so that signal separation can be achieved in the frequency domain, but also the joint channel estimation and partitioning for all users is completed in the time domain via circular convolution, therefore, the receiver can restore the data for every user.

The remaining paper is organized as follows. Section II illustrates the system model of the proposed TDS-OFDMA scheme. Taking advantage of the new "time-space two- dimensional frame structure" presented in section III for the proposed TDS-OFDMA scheme, the joint cyclicity reconstruction for all users and signal separation in frequency domain

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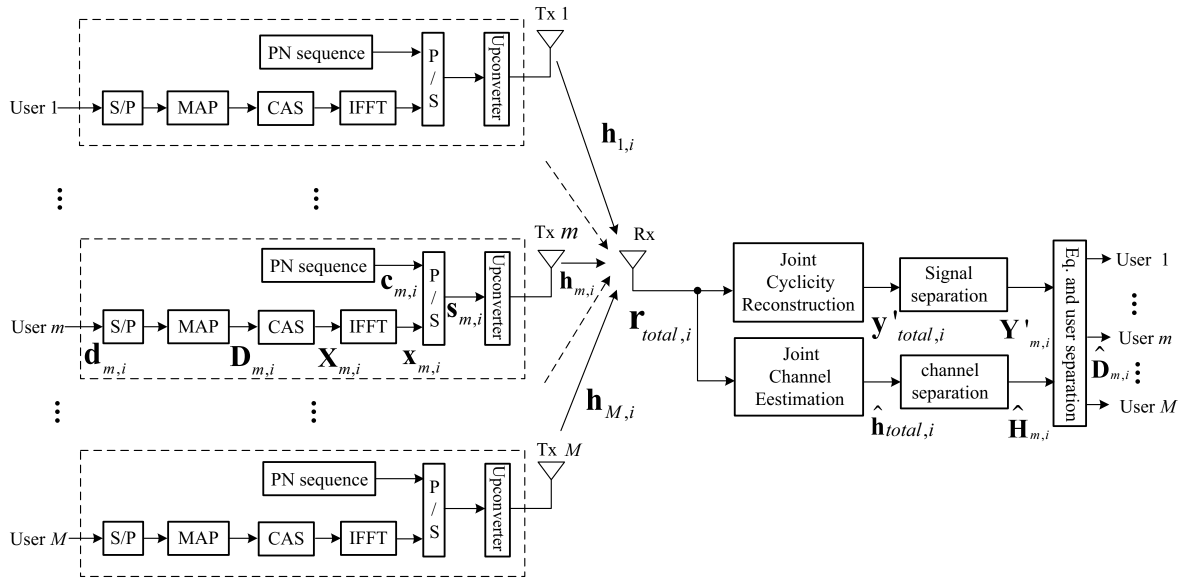


Fig. 1. System model of the proposed TDS-OFDMA scheme.

is presented in section IV, and the joint channel estimation method in the time domain is derived in section V, respectively. Section VI shows the simulation results to verify the feasibility and system performance of the proposed scheme. We then conclude this paper in section VII.

II. SYSTEM MODEL OF TDS-OFDMA

Fig. 1 shows a general discrete-time system model of the proposed TDS-OFDMA scheme, where M users simultaneously transmit their signals to a central base station.

For the mth user in the proposed TDS-OFDMA system, each block $\mathbf{d}_{m,i}$ of L_m information symbols after serial-to-parallel (S/P) conversion is fed to the MAP unit for QPSK/m-QAM modulation to generate the frequency-domain data $\mathbf{D}_{m,i} = \{D_{m,i}(n)\}_{n=0}^{L_m-1}$ in the ith signal frame. Then the carrier assignment scheme (CAS) unit maps $\mathbf{D}_{m,i}$ onto the sub-carriers assigned to the corresponding user by extending $\mathbf{D}_{m,i}$ with the insertion of $N - L_m$ zeros and results in an N-dimensional vector $\mathbf{X}_{m,i} = \{X_{m,i}(n)\}_{n=0}^{N-1}$ with entries

$$X_{m,i}(n) = \begin{cases} D_{m,i}(n) & n \in \Gamma_m \\ 0 & otherwise \end{cases}, \tag{1}$$

where Γ_m is the sub-carrier set of the mth user. Clearly, to avoid that a given sub-carrier is shared by different users, all these sets $\{\Gamma_m\}_{m=1}^{M}$ must be mutually exclusive, i.e.,$\Gamma_i \cap \Gamma_j = \phi$ for $i \neq j$.

After IDFT operation of $\mathbf{X}_{m,i}$, we get the time-domain data symbols $\mathbf{x}_{m,i}$ whose entry $x_{m,i}(n)$ can thus be written as

$$x_{m,i}(n)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_{m,i}(k)\exp\left\{j\frac{2\pi nk}{N}\right\} \quad 0\le n\le N-1. \tag{2}$$

The ith basic TDS-OFDM signal frame of the mth user $\mathbf{s}_{m,i} = \{s_{m,i}(n)\}_{n=0}^{N_f-1}$ is then obtained as the serial concatenation of the N_g-point PN sequence $\mathbf{c}_{m,i}$ (will be discussed in detail in section III) and data symbols $\mathbf{x}_{m,i}$, and takes the form

$$s_{m,i}(n) = \begin{cases} c_{m,i}(n) & 0 \le n \le N_g - 1 \\ x_{m,i}(n) & N_g \le n \le N_f - 1 \end{cases}, \tag{3}$$

where $N_f = N + N_g$.

Each signal frame is parallel-to-serial (P/S) converted and then up-converted for transmission. After passing through a multi-path channel with channel impulse response (CIR) denoted by $\mathbf{h}_{m,i} = \{h_{m,i}(l)\}_{l=0}^{l_m-1}$, where l_m is the maximum delay spread, the received blocks corresponding to the PN sequence $\mathbf{c}_{m,i}$ and IDFT block $\mathbf{x}_{m,i}$ can be represented by $g_{m,i}(n)$ and $y_{m,i}(n)$, respectively

$$g_{m,i}(n) = c_{m,i}(n) * h_{m,i}(n) \quad 0 \le n < N_g + l_m - 1, \tag{4}$$

$$y_{m,i}(n) = x_{m,i}(n) * h_{m,i}(n) \quad 0 \le n < N + l_m - 1, \tag{5}$$

where $*$ denotes linear convolution.

Intuitively, $\{g_{m,i}(n)\}_{n=N_g}^{N_g+l_m-2}$ is the interference form PN sequence to IDFT block and $\{y_{m,i}(n)\}_{n=N}^{N+l_m-2}$ is the interference from IDFT block to the next PN sequence. Some iterative methods with high complexity have been proposed to remove the ISI and then reconstruct the cyclicity of the received IDFT block for CE and equalization in the conventional single-user TDS-OFDM system [12]-[14]. However, in the TDS-OFDMA system, the interferences caused by different users are implicitly superposed at the receiver, dismiss the possibility of the interferences cancellation by the iterative interference subtraction method that is already complex enough. Therefore, signal separation for different users is very difficult in TDS-OFDMA system.

Confronting the difficulty of interference cancellation in TDS-OFDMA system, this paper firstly proposes the new "time-space two-dimensional frame structure" taking both the time dimension and space (different users locates at different

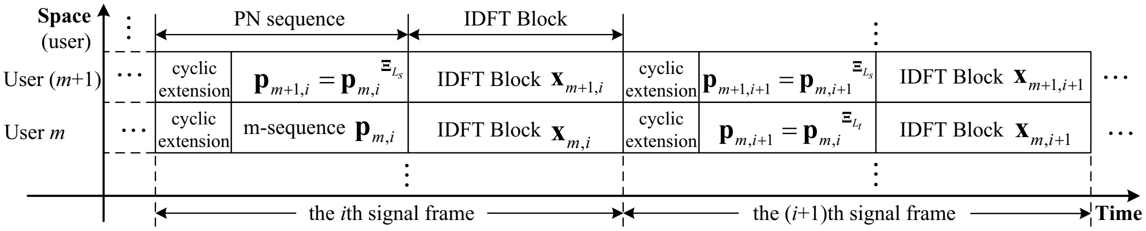


Fig. 2. "Time-space two-dimensional frame structure" of the proposed TDS-OFDMA system.

places) dimension into consideration, which will be discussed in detail in section III.

At the receiver of the TDS-OFDMA system, on one hand, as presented later in section IV, jointly cyclicity reconstructed signal $\mathbf{y}'_{total,i}$ of the received OFDM data for all the users is obtained via one-step simple add-subtract operation, and then the multiple access signal can be orthogonally separated in frequency-domain to acquire the frequency-domain signal $\mathbf{Y}'_{m,i}$ for each user, whose entries take the form

$$Y'_{m,i}(n) = H_{m,i}(n)\cdot X_{m,i}(n) + W_{m,i}(n) \quad 0 \le n \le N-1, \quad (6)$$

where $W_{m,i}(n)$ is the complex-valued additive white Gaussian noise (AWGN) in the frequency domain, $\mathbf{H}_{m,i} = \{H_{m,i}(n)\}_{n=0}^{N-1}$ is the N-point DFT of the CIR $\mathbf{h}_{m,i}$, and is given by

$$H_{m,i}(n) = \sum_{l=0}^{l_m-1} h_{m,i}(l)\cdot \exp\left\{-j\frac{2\pi nl}{N}\right\} \quad 0 \le n \le N-1. \quad (7)$$

On the other hand, as derived later in section V, joint channel estimation will generate the equivalent "total" CIR $\widehat{\mathbf{h}}_{total,i}$, and orthogonal separation of the CIRs for multiple users can be achieved in the time domain to get the CE results of $\widehat{\mathbf{H}}_{m,i}$ for each user.

After the signal separation and CE for each user are achieved, channel equalization can be easily performed through a bank of one-tap dividers to restore the transmitted signal for each user [3]:

$$\widehat{\mathbf{D}}_{m,i} = \frac{\mathbf{Y}'_{m,i}}{\widehat{\mathbf{H}}_{m,i}} \quad 1 \le m \le M \ , \quad (8)$$

where $\widehat{\mathbf{D}}_{m,i}$ is the estimation of the frequency-domain transmitted data $\mathbf{D}_{m,i}$ for user m.

III. TIME-SPACE TWO-DIMENSIONAL FRAME STRUCTURE

In this section, the new "time-space two-dimensional frame structure" is proposed for the TDS-OFDMA system.

As shown in Fig. 2, each signal frame is composed of an IDFT block and a PN sequence. The PN sequence of the ith signal frame for the m th user $\mathbf{c}_{m,i} = \{c_{m,i}(n)\}_{n=0}^{N_g-1}$ is the L_t-symbol cyclically extended version of the m-sequence $\mathbf{p}_{m,i} = \{p_{m,i}(n)\}_{n=0}^{N_p-1}$:

$$c_{m,i}(n) = \begin{cases} p_{m,i}(N_p - L_t + n) & 0 \le n \le L_t - 1 \\ p_{m,i}(n - L_t) & L_t \le n \le N_g - 1 \end{cases}, \quad (9)$$

where $N_g = N_p + L_t$.

In the time dimension of the "time-space two-dimensional frame structure", the m-sequences between adjacent frames are neither identical nor holding a special phase offset sequence of 1,-2,3,-4, ..., 111, -112, 112, -111, ..., 4,-3,2,-1, as specified in [9], but adopt a constant phase offset L_t. In the space dimension, the m-sequences between neighboring users similarly hold a constant offset L_s :

$$\begin{cases} \mathbf{p}_{m,i+1} = \mathbf{p}_{m,i}^{\Xi_{L_t}} \\ \mathbf{p}_{m+1,i} = \mathbf{p}_{m,i}^{\Xi_{L_s}} \end{cases}, \quad (10)$$

where $\mathbf{p}_{m,i}$ is the m-sequence of user m in the ith frame, $\mathbf{p}^{\Xi_L}$ denotes the L-symbol circular shift of the vector $\mathbf{p}$. That is

$$\mathbf{p}^{\Xi_L} = [p(L), p(L+1), ..., p(N_p-1), p(0), ..., p(L-1)]. \quad (11)$$

The reason why we design such frame structure is to facilitate the joint cyclicity reconstruction and CE at the receiver, both of which will be presented in detail in the following parts.

Firstly, let us analyze the properties of the "time-space two-dimensional frame structure" in the time dimension.

From (9) and (10), the relationship between the PN sequence of the $(i+1)$th signal frame $\mathbf{c}_{m,i+1}$ and the m-sequence of the ith signal frame $\mathbf{p}_{m,i}$ should be

$$c_{m,i+1}(n) = \begin{cases} p_{m,i}(n) & 0 \le n \le N_p - 1 \\ p_{m,i}(n - N_p) & N_p \le n \le N_g - 1 \end{cases}. \quad (12)$$

Equations (9) and (12) indicate the last N_p samples of the GI of the ith signal frame ($\mathbf{c}_{m,i}$) are identical to the first N_p symbols of the GI of the $(i+1)$th signal frame ($\mathbf{c}_{m,i+1}$). That is to say, the IDFT block of the ith signal frame $\mathbf{x}_{m,i}$ is enclosed by two identical m-sequences $\mathbf{p}_{m,i}$ (we refer to those three blocks as "virtual frame"). This feature is guaranteed by the fact that the phase offset L_t in the time dimension between $\mathbf{p}_{m,i}$ and $\mathbf{p}_{m,i+1}$ is the same as the cyclic extension length of the PN sequence in the "time-space two-dimensional frame structure". In the following section IV, we will show how this useful designed feature is used to facilitate the joint cyclicity reconstruction of the OFDM data at the receiver.

IV. JOINT CYCLICITY RECONSTRUCTION

Under the assumption of ideal synchronization at the receiver, the implicitly combined signal of the total M users $r_{total,i}(n)$ in the TDS-OFDMA system is the linear superposition of the received signal $r_{m,i}(n)$ corresponding to the "virtual frame" for each user, as shown in Fig. 3(a), and can be expressed by

$$r_{total,i}(n) = \sum_{m=1}^{M} r_{m,i}(n) \quad 0 \le n \le N + 2N_p - 1. \quad (13)$$

The following add-subtract operation of received signal $\mathbf{r}_{total,i}$ would produce a new sequence $y'_{total,i}(n)$

$$y'_{total,i}(n) = \begin{cases} r_{total,i}(n+N_p)+r_{total,i}(n+N+N_p)-r_{total,i}(n) & 0\le n\le N_p-1 \\ r_{total,i}(n+N_p) & N_p\le n\le N-1 \end{cases} \tag{14}$$

Substitute (13) into (14), we have

$$y'_{total,i}(n) = \begin{cases} \sum\limits_{m=1}^{M} r_{m,i}(n+N_p) + r_{m,i}(n+N+N_p)-r_{m,i}(n) & 0\le n\le N_p-1 \\ \sum\limits_{m=1}^{M} r_{m,i}(n+N_p) & N_p\le n\le N-1 \end{cases} \tag{15}$$

Since the PN sequence is the cyclically extended version of the m-sequence, the "tails" part of user m (shadow area with vertical lines in Fig. 3(b)) in $\{r_{m,i}(n)\} \begin{matrix} l_m-1 \\ n=0 \end{matrix}$ and $\{r_{m,i}(n)\} \begin{matrix} N_p+l_m-1 \\ n=N_p \end{matrix}$ should be the same, assuming the CIR variation during one signal frame is negligible and $l_m \le L_t \le N_p$. Therefore, (15) leads to

$$y'_{total,i}(n) = \sum_{m=1}^{M} y'_{m,i}(n) \quad 0 \le n \le N \;\; -1, \tag{16}$$

where

$$y'_{m,i}(n) = \begin{cases} y_{m,i}(n+N) + y_{m,i}(n)+v_{m,i}(n) & 0\le n\le l_m-1 \\ y_{m,i}(n)+v_{m,i}(n) & l_m\le n\le N-1 \end{cases}. \tag{17}$$

As shown in Fig. 3(b), $y'_{m,i}(n)$ shares the exactly same form as that of the IDFT block in CP-OFDM systems. Therefore, it is the cyclicity reconstructed signal of the received OFDM data for user m.

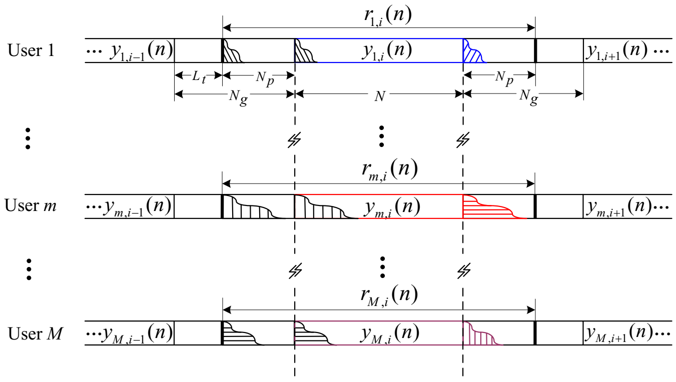
Intuitively, the new sequence $y'_{total,i}(n)$ Fig. 3(c) has the cyclicity property just like that in the CP-OFDMA system, since is the linear combination of $\{y'_{m,i}(n)\}_{m=1}^{M}$, where each $y'_{m,i}(n)$ holds the cyclicity property. As a result, joint cyclictiy reconstruction for all users is completed. The N-point DFT of $\mathbf{y}'_{total,i} = \left\{y'_{total,i}(n)\right\}_{n=0}^{N-1}$ is $\mathbf{Y}'_{total,i}$ with entries

$$Y'_{total,i}(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} y'_{total,i}(k) \exp\left\{-j\frac{2\pi nk}{N}\right\}. \tag{18}$$

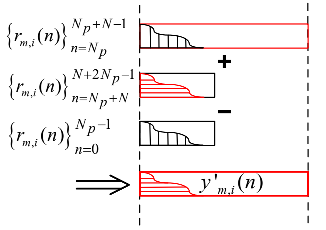
According to the same CAS at the transmitter, the frequency-domain signal $\mathbf{Y}'_{m,i} = \{Y'_{m,i}(n)\}_{n=0}^{N-1}$ for channel equalization and data detection in (8) is selected out of $\mathbf{Y}'_{total,i}$ for user m

$$Y'_{m,i}(n) = \begin{cases} Y'_{total,i}(n) & n \in \Gamma_m \\ 0 & n \notin \Gamma_m \end{cases} \quad 1 \le m \le M \;. \tag{19}$$

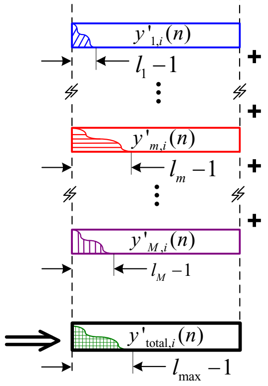
Because the sub-carrier set for each user is mutually orthogonal, the linearly combined signal for multiple users in the time domain is orthogonally separated in the frequency domain.



(a) Received signal for M users



(b) Cyclicity reconstruction for user m



(c) Joint cyclicity reconstruction for M users

Fig. 3. Joint cyclictiy reconstruction of the implicitly combined data for all the users in the TDS-OFDMA system.

After signal separation is achieved by joint cyclicity reconstruction, we must obtain the CE for data restoration for each user, which is the object of the following section.

V. JOINT CHANNEL ESTIMATION AND SEPARATION

To get the CE for each user, let's secondly analyze the feature of the "time-space two-dimensional frame structure" in the space dimension. In Fig. 2, the m-sequences for different users locating at their own places satisfy (10), thus

$$\mathbf{p}_{m,i} = \mathbf{p}_{1,i}^{\mathbf{\Xi}_{(m-1)\cdot L_s}} \quad 1 \le m \le M \;\; . \tag{20}$$

Since m-sequence has very good auto-correlation property and satisfies

$$\mathbf{p}_{m,i} \otimes \mathbf{p}_{m,i} \approx N_p \cdot \delta(n) \quad 1 \le m \le M \;\; , \tag{21}$$

where $\otimes$ denotes circular convolution, and $\delta(n)$ denotes the Dirac function.

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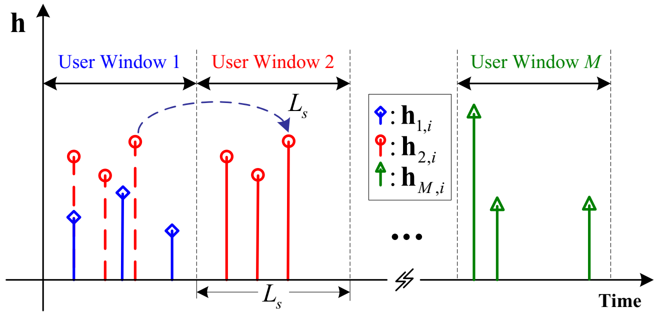

Fig. 4. Orthogonal separation of the CIRs in the time domain and "User Window" in the proposed TDS-OFDMA system.

The cross-correlation function between $\mathbf{p}_{j,i}$ and $\mathbf{p}_{k,i}$ is

$$\mathbf{p}_{j,i} \otimes \mathbf{p}_{k,i} \approx N_p \cdot \delta[n-(j-k)\cdot L_s] \quad 1 \le j,k \le M \ . \tag{22}$$

The received m-sequence for each user intrinsically enjoys the cyclicity property because of the cyclically extended structure in Fig. 2. Therefore, the actual received m-sequence at the receiver in the ith frame $\mathbf{q}_i = \{r_{total,i}(n)\}_{n=0}^{N_p-1}$, which is the linear superposition of all received m-sequences for M users, also holds the cyclicity property and takes the form

$$\mathbf{q}_i = \sum_{m=1}^{M} \mathbf{p}_{m,i} \otimes \mathbf{h}_{m,i} + \mathbf{v}_i, \tag{23}$$

where the vector $\mathbf{v}_i$ is the AWGN in the ith frame.

Use a local m-sequence $\mathbf{p}_{1,i}$ to do circular convolution with $\mathbf{q}_i$, we can get the rearranged "total" CIR $\widehat{\mathbf{h}}_{total,i}$

$$\begin{aligned}\widehat{\mathbf{h}}_{total,i} &= \mathbf{q}_i \otimes \mathbf{p}_{1,i} \approx \left(\sum_{m=1}^{M} \mathbf{p}_{m,i} \otimes \mathbf{h}_{m,i}\right) \otimes \mathbf{p}_{1,i} \\ &\approx N_p \cdot \sum_{m=1}^{M} \mathbf{h}_{m,i} \cdot \delta[n-(m-1)\cdot L_s].\end{aligned} \tag{24}$$

Intuitively, equation (24) shows that $\mathbf{h}_{m,i}$ is shifted by $(m-1)\cdot L_s$ symbols in the time domain. If $l_{\max} = \max(\{l_m\}_{m=1}^{M}) \le L_s$ and $M \cdot L_s \le N_p$, the shifted $\{\mathbf{h}_{m,i}\}_{m=1}^{M}$ are non-overlapping in the time domain, which means that the CIRs corresponding to M different users are orthogonally separable by each "User Window" in Fig. 4. The function of the mth "User Window" is $\mathbf{w}_{m,i}$

$$\mathbf{w}_{m,i} = \sum_{n=1}^{L_s} \delta[n-(m-1)\cdot L_s] \quad 1 \le m \le M. \tag{25}$$

Multiply $\mathbf{w}_{m,i}$ with $\widehat{\mathbf{h}}_{total,i}$, and then we get the CE $\widehat{\mathbf{h}}_{m,i}$ for the mth user

$$\begin{aligned}\widehat{\mathbf{h}}_{m,i} &= \frac{1}{N_p} \cdot \mathbf{w}_{m,i} \cdot \left(\widehat{\mathbf{h}}_{total,i}\right) \\ &\approx \left(\sum_{n=1}^{L_s} \delta[n-(m-1)\cdot L_s]\right) \cdot \left(\sum_{m=1}^{M} \mathbf{h}_{m,i} \cdot \delta[n-(m-1)\cdot L_s]\right) \\ &\approx \mathbf{h}_{m,i} \quad 1 \le m \le M \ .\end{aligned} \tag{26}$$

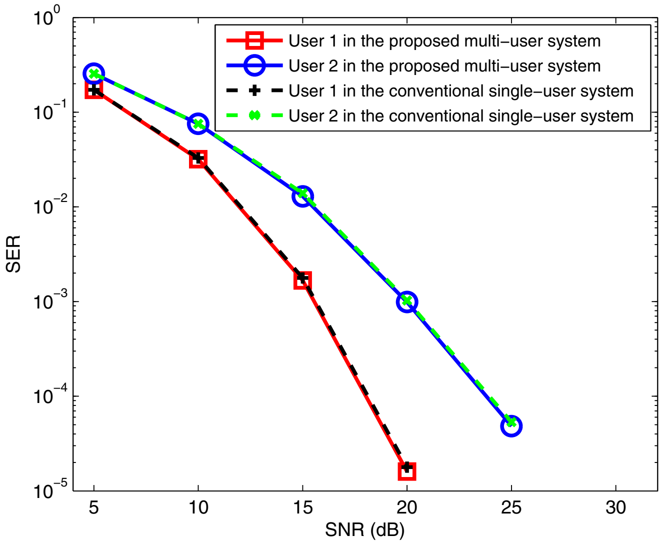

Fig. 5. SER performance vs. SNR for each user in the proposed TDS-OFDMA system.

It is worthwhile to point out that any local m-sequence can be used for joint CE, i.e., $\mathbf{p}_{m,i}$ $(1 \le m \le M)$, and the circular convolution operation can also be replaced by circular correlation or FFT to improve the computational efficiency.

After $\widehat{\mathbf{h}}_{m,i}$ is obtained for each user, signal restoration can be completed via (8) for each user.

VI. PERFORMANCE EVALUATION

Simulations are performed to verify the feasibility and the performance of the proposed TDS-OFDMA system. The following parameters are assumed: 1) $M = 2$ and available $N = 3780$ sub-carriers with each sub-carrier modulated in QPSK constellation are equally assigned to two users; 2) Sub-carrier spacing is 2 kHz; 3) A baseband symbol rate of 7.56 M symbol/s; 4) The length of the m-sequence is $N_p = 255$; 5) Phase shift of the m-sequence in the time dimension is $L_t = 153$, and $L_s = 76$ in the space dimension; 6) Two typical multi-path channel models, Brazil A and Brazil D [16], are used for system simulation; 7) The channel for user 1 is Brazil A and Brazil D for user 2, independently.

For the purpose of comparison, we also provide the system symbol error rate (SER) performance of the conventional single-user TDS-OFDM system with the same channels, where all the available sub-carriers are used by only one user.

Fig. 5 presents the SER performance both for the conventional single-user TDS-OFDM system and the proposed TDS-OFDMA system without coding and decoding. The simulation results indicate that each user of the proposed TDS-OFDMA system can approach almost the same SER performance as the single-user system. It also shows that the SER performance has deteriorated a lot for channel Brazil D, since the multi-path distortion for Brazil D is more severe than that for Brazil A.

Fig. 6 shows the SER comparison of those two systems in Brazil D Rayleigh fading channel (the maximum Doppler shift of the channel is 30 Hz). It is obvious that the proposed

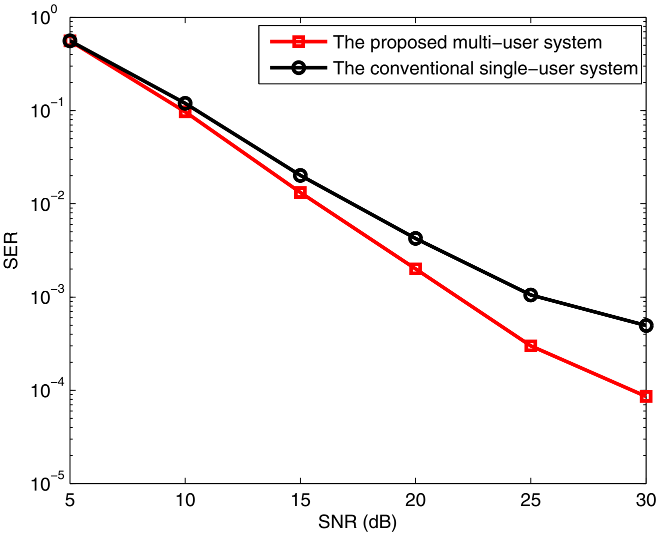

Fig. 6. SER performance comparison between the conventional single-user TDS-OFDM system and the proposed TDS-OFDMA system.

system holds better SER performance in mobile environment when compared with the conventional single-user system. For example, the required SNR of the conventional single-user TDS-OFDM system is 25 dB if the target SER is 0.001, while the SNR needed of the proposed system decreased to 22dB for the same SER target.

The rationale behind the better performance is that, the joint cyclicity reconstruction proposed in this paper does not need any channel information at all. Consequently, it avoids the conventional iterative interference cancellation between the GI and OFDM data, which is not only complex, but also accumulates errors caused by imperfect CE during iteration. More errors of the CE, caused by mobile environment, would lead to more severe performance degradation.

It should be pointed out that, compared with the conventional TDS-OFDM system, the requirements of $l_{\max} \leq L_s$ and $M \cdot L_s \leq N_p$ on the proposed joint CE method of the proposed TDS-OFDMA scheme in section V lead to two implementation strategies of the proposed TDS-OFDMA scheme. On one hand, if the same transmission efficiency is required, the maximum delay spread the proposed scheme can support will decrease, which is inversely proportional to the number of active users M. On the other hand, if the capability to combat the same delay spread is needed, the PN sequence of longer length should be used and thus leads to a certain loss of system transmission efficiency.

VII. CONCLUSION

A novel TDS-OFDMA scheme is proposed in this paper, together with the new "time-space two-dimensional frame structure". The corresponding receiver design including joint cyclicity reconstruction of the received OFDM data and joint CE for all users are also derived. Theoretical analysis and computer simulation show that, the proposed system firstly overcomes the major difficulty that the mixed interferences between different frame bodies and GIs caused by multiple users are hardly to be eliminated in TDS-OFDMA systems, and it also provides the multiple access capability with even better system performance in mobile environment compared with the conventional single-user TDS-OFDM system at the expense of longer PN length. Therefore, the proposed TDS-OFDMA scheme could be another baseline technology for the bidirectional, multi-user applications, such as interactive digital TV and cellular wireless systems.

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