An Interference Cancellation Scheme for The Multiuser TRDMA Uplink System

Feng Han and K. J. Ray Liu,
Department of ECE, University of Maryland, College Park, MD, 20742, USA
Origin Wireless Communications, College Park, MD, 20740, USA
Email: {hanf, kjrliu}@umd.edu

***Abstract*—The concept of Time Reversal Division Multiple Access (TRDMA) has recently been proposed as a promising medium access technology for the multi-user wireless broadband communications. Compared with the existing multi-carrier technology like OFDM/OFDMA, the TRDMA provides a cost-effective single-carrier alternative technology to combat the inter-symbol interference (ISI) for broadband communications, and at the same time leverages the degrees of freedom in a large number of multi-paths to form a unique high-resolution spatial focusing effect. Previous work on TRDMA mainly focus on the multi-user downlink system. In this paper, we first introduce a TRDMA-based multi-user uplink architecture and then propose a 2-dimensional (2D) parallel interference cancellation scheme to further enhance the system performance. The TRDMA uplink architecture keeps the cost of end-users at a minimum level, and reuses the processing power at the base station (BS) that has already been made available for the downlink. The proposed 2D parallel interference cancellation scheme utilizes the tentative decisions of detected symbols to effectively cancel the interference in both the time domain (i.e. ISI) and the user domain (i.e. inter-user interference (IUI)), which significantly improve the bit-error-rate performance in the high signal-to-noise-ratio (SNR) regime. Simulation results are provided and compared with the basic TRDMA system without interference cancellation.**

***Index Terms*—Time Reversal, TRDMA, interference cancellation**

I. Introduction

Very recently, the concept of time reversal division access (TRDMA) was introduced as a novel multi-user media access scheme for broadband communication systems [1]. The broadband communications over channels with large delay spread can be very challenging due to the severe inter-symbol interference (ISI). Conventionally, complicated multi-carrier techniques (like OFDM/OFDMA) are used to alleviate ISI [2]–[5]. Leveraging the unique temporal and spatial focusing effects of the time reversal (TR) phenomenon [6], [7], the TRDMA provides a cost-effective single-carrier alternative for broadband multi-user communications. The TRDMA scheme uses the multi-path channel profile associated with each user's location as a location-specific signature for the user. In essence, each path of the multi-path channel is treated as a virtual antenna in the TRDMA, which collectively results in very high-resolution spatial focusing with "pin-point" accuracy. Meanwhile, the temporal focusing effect effectively suppresses ISI which significantly simplifies the terminal user's complexity and gives rise to higher-speed data transmission.

The authors in paper [1] focused on a broadband multi-user downlink system based on the TRDMA concept. In such a TRDMA downlink system, the base station (BS) transmit multiple simultaneous data streams to different users, each of which is associated with a unique multi-path profile of its channel in rich-scattering environments. The TRDMA downlink scheme exploits the spacial degrees of freedom of the environment, and focuses the useful signal power only at the intended locations. The time reversal mirrors (TRMs) [8], [9] at the BS first *time-reverse*[1] the channel impulse response (CIR) of each user's channel as the user's signature waveform, and then embed these signatures into the corresponding data streams. The transmitted signal from the BS in the TRDMA downlink is a mixed signal consisting of all the users' data. When such a combined signal propagates to a certain user through the corresponding multi-path channel, the power of the useful signal component that carries this user's data will automatically be boosted out of the combination thanks to the spatial focusing effect. Within the TRDMA framework, more sophisticated signature waveforms than the basic TR-waveform can be derived based on the multi-path channel responses to further improve the performance of the TRDMA downlink system, when additional computational complexity is affordable at the BS [10]. One very desirable feature of the TRDMA downlink scheme proposed in [1] is that most of the complexity can be shifted to the BS side, facilitating the extremely low complexity at the end-users.

In line with the same design philosophy of minimizing the complexity of the terminal users, a TRDMA based uplink scheme can be developed. As one will see in this paper, the proposed TRDMA uplink scheme shares a strong duality in the mathematical structure with the downlink without increasing the complexity of the end-users. And as such, an equivalent *spacial focusing* effect (although not physically in the space domain) can be observed in the user's signature domain at the BS. Similar to in the downlink scheme, the equivalent spacial focusing effect enables the BS to use the user's TR signature waveform to extract the useful component out of the combined received signal, allowing multiple users accessing the BS simultaneously. Additionally, unlike many other conventional communications paradigms that adopt symmetric architectures, the proposed uplink scheme shares the same processing power and channel knowledge at the BS with the

[1] i.e. to rearrange the received waveform reversely over time.

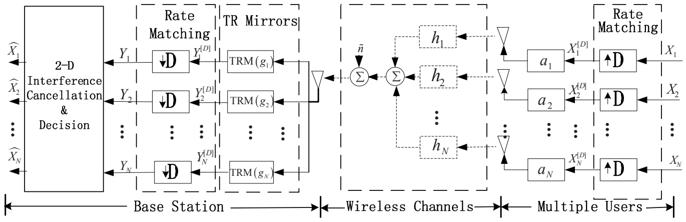

Fig. 1. The diagram of SISO TRDMA multiuser uplink system

downlink, keeping the end-user's complexity at the minimum level.

To further enhance the system performance of the TRDMA uplink, we propose a 2-dimensional (2D) parallel interference cancellation scheme by exploring the signal structure of both the inter-symbol interference (time dimension) and the inter-user interference (IUI) (user dimension). Compared with the existing multi-user detection (MUD) techniques for CDMA systems [11]–[18], the interference cancellation for the TRDMA system is complicated and made more desirable by the following two facts: First, the multi-path signature waveforms are not naturally orthogonal, thus more severe IUI is expected in TRDMA than in CDMA system; Second, the TRDMA system allows overlap between the transmitted signature waveforms to boost system throughput, which will cause ISI depending on the extent of overlapping.

In this paper, we introduce a multi-user uplink scheme based on the concept of TRDMA and propose a 2D parallel interference cancellation technique for the TRDMA uplink system. Bearing a strong duality with the TRDMA downlink, the introduced TRDMA uplink scheme reuses the processing power at the base station (BS) that has already been made available for the downlink, and keeps the complexity of the terminal users at a minimal level. The proposed 2D parallel interference cancellation scheme utilizes the tentative decisions of detected symbols to effectively cancel both the ISI and IUI at the BS. Simulation results are provided and compared with the basic TRDMA system without interference cancellation.

II. TRDMA Uplink System

Consider a multi-user broadband communication system that consists of a BS and N users in the multi-path environment. In this paper, we assume that all the users operate over the same frequency band and use TRDMA to separate from one another.

Fig. 1 shows the block diagram of the TRDMA uplink scheme. As shown in Fig. 1, N users simultaneously transmit independent bit streams to the BS. In this paper, we assume that the Binary Phase-Shift Keying (BPSK) modulation is used, and thus the polarity of the modulated symbols $\{X_i[k] \in \{-1,+1\}\}$ carries the binary information for User i.

For any given User i in the uplink network, the channel h_i between the BS and User i is a multi-path channel characterized by a unique discrete-time[2] channel impulse response (CIR):

$$h_i[k] = \sum_{l=0}^{L-1} h_{i,l}\delta[k-l], \tag{1}$$

where $h_{i,l} \in \mathbb{R}$ is the l-th tap of the CIR with length L, and $\delta[\cdot]$ is the Dirac delta function. We assume that the channels are quasi-static and reciprocal, which can be acquired at the BS through a channel probing phase [1], [6]. During the channel probing phase, each user takes turns to send impulse signal[3] to the BS so that the channel impulse response (CIR) $\{h_i[k]\}$ of each user's link can be recorded by the TRM at the BS. Upon recording the CIR, the TRM will reverse the recorded waveform in the time-domain and normalize it as the unique signature waveform of User i [1]. The time-reversed waveform of User i will be used in the data transmission phase to extract the desired signal from a combination of the multiple access signals that are mixed in the air. Specifically, the time-reversed signature waveform of User i can be written as

$$g_i[k] = h_i[L-1-k] \Big/ \sqrt{\sum_{l=0}^{L-1} |h_i[l]|^2}\ . \tag{2}$$

After the channel probing phase, the users can start to transmit the statistically independent messages $\{X_1(k), X_2(k), \cdots, X_N(k)\}$ to the BS through the multi-path channels. A rate back-off factor D is introduced to match the symbol rate (signal bandwidth) with the much higher system's sampling rate (channel bandwidth). For any user U_i, $i \in \{1,2,\ldots,N\}$, the rate matching process is performed by up-sampling the sequence of modulated symbols $\{X_i[k]\}$ by a factor D, as shown in Fig. 1. The up-sampled sequence of modulated symbols for User i can be expressed as

$$X_i^{[D]}[k] = \begin{cases} X_i[k/D], & \text{if } \ k \ mod \ D \ = \ 0, \\ 0, & \text{if } \ k \ mod \ D \ \neq \ 0. \end{cases} \tag{3}$$

The scaling factors a_i, for $i \in \{1,2,\ldots,N\}$ in Fig. 1 are used to implement the transmit power control, whose values are assumed to be instructed by the BS through the feedback/control channel. After multiplying with scaling factor, the sequence of $a_i X_i^{[D]}[k]$ for all $i \in \{1,2,\ldots,N\}$, is transmitted through the corresponding multi-path channel $\{h_i[k]\}$.

When the sequence $\{a_i X_i^{[D]}[k]\}$ propagates through its wireless channel $\{h_i[k]\}$, the convolution between $\{a_i X_i^{[D]}[k]\}$ and the CIR $\{h_i[k]\}$ is automatically taken as the channel output for User i. Then, all of the channel outputs for the N users are mixed together in the air plus the additive white Gaussian noise (AWGN) $\tilde{n}[k]$ at the BS with zero mean and variance σ_N^2, as illustrated in Fig. 1. Consequently, the mixed signal received at the BS can be written as

$$S[k] = \sum_{i=1}^{N} a_i \left(h_i * X_i^{[D]}\right)[k] + \tilde{n}[k]. \tag{4}$$

Upon receiving the mixed signal as shown in (4), the BS passes this mixed signal through a bank of N TRMs, each

[2]as a result of the analog-to-digital convertor (ADC)

[3]Although it is difficult to send an ideal impulse in practice which would require infinite bandwidth, a modified raise-cosine signal can be a good candidate for limited bandwidth for this purpose [6]

of which performs the convolution between its input signal $\{S[k]\}$ and the user's signature waveform $\{g_i[k]\}$. Such a convolution using the signature waveform exacts the useful signal component and suppress the signals of other users. As the output of the i-th TRM, the convolution of $\{S[k]\}$ and the signature of User i $\{g_i[k]\}$ can be represented as

$$\begin{aligned} Y_i^{[D]}[k] &= \sum_{j=1}^{N} a_j \left(g_i * h_j * X_j^{[D]} \right)[k] + \left(g_i * \tilde{n} \right)[k] \\ &= \sum_{j=1}^{N} \sum_{l=0}^{2L-2} a_j \left(g_i * h_j \right)[l] X_j^{[D]}[k-l] + \left(g_i * \tilde{n} \right)[k], \end{aligned} \tag{5}$$

in which the highest gain for User i's symbol is achieved at the temporal focusing time $l = L-1$, with

$$\left(g_i * h_i \right)[L-1] = \sqrt{\sum_{l=0}^{L-1} |h_i[l]|^2}. \tag{6}$$

Examining the equation (5) and the received signal at the terminal users in the downlink [1], the same mathematical structure can be found by switching the roles of the signature waveforms $\{g_i\}$s and the CIRs h_is in the convolution (and ignoring the scaling factor a_i and noise term.) Therefore, mathematically[4], an equivalent spatial focusing effect as observed in the downlink can be seen in the user's signature domain of the proposed uplink scheme. Such a equivalent spatial focusing effect is used to separate the useful signal from the signals from others. Then the rate matching is performed by down-sampling (with the same factor D) the TRMs' output signal to recover the original symbol rate of the modulated symbols of each user.

After the rate matching, the down-sampled TRM output $Y_i[k]$ can be obtained as[5]

$$Y_i[k] = \sum_{j=1}^{N} \sum_{l=-\lfloor \frac{L-1}{D} \rfloor}^{\lfloor \frac{L-1}{D} \rfloor} a_j \left(g_i * h_j \right)[L-1+Dl] X_j[k-l] + n_i[k], \tag{7}$$

where the colored noise $n_i[k] = \sum_{l=0}^{L-1} g_i[l] \tilde{n}[Dk-l] = \underline{g}_i \underline{\tilde{n}}[k]$ with $\underline{g}_i \triangleq \left[g_i[0], g_i[1], \cdots, g_i[L-1] \right]$ and $\underline{\tilde{n}}[k] \triangleq \left[\tilde{n}[k], \tilde{n}[k-1], \ldots, \tilde{n}[k-L+1] \right]^T$. Note that the colored noise $\{n_i[k]\}$ is still a Gaussian random variable with zero mean and the same variance σ_N^2, since $\{g_i\}$ is a normalized waveform as shown in (2).

Decomposing the signal shown in (7), we have the following components as

$$\begin{aligned} Y_i[k] &= a_i \left(g_i * h_i \right)[L-1] X_i[k] && (Signal) \\ &+ a_i \sum_{\substack{l=-\lfloor \frac{L-1}{D} \rfloor \\ l \neq 0}}^{\lfloor \frac{L-1}{D} \rfloor} \left(g_i * h_i \right)[L-1+Dl] X_i[k-l] && (ISI) \\ &+ \sum_{\substack{j=1 \\ j \neq i}}^{N} a_j \sum_{l=-\lfloor \frac{L-1}{D} \rfloor}^{\lfloor \frac{L-1}{D} \rfloor} \left(g_i * h_j \right)[L-1+Dl] X_j[k-l] && (IUI) \\ &+ n_i[k]. && (Noise) \end{aligned} \tag{8}$$

The basic TRDMA uplink scheme uses the signal $Y_i[k]$ in (7) to estimate the transmitted symbol $X_i[k]$. A very simple decision rule can be derived to implement the maximum-likelihood estimation (MLE) for the BPSK symbols $X_i[k] \in \{+1, -1\}$ for $i = 1, 2, \ldots, N$. By the central limit theorem, we model the total interference term (including the ISI and IUI) as a Gaussian random variable with zero mean[6] and variance

$$\begin{aligned} \sigma_{I,i}^2 = |a_i|^2 & \sum_{\substack{l=-\lfloor \frac{L-1}{D} \rfloor \\ l \neq 0}}^{\lfloor \frac{L-1}{D} \rfloor} \left| \left(g_i * h_i \right)[L-1+Dl] \right|^2 \\ &+ \sum_{\substack{j=1 \\ j \neq i}}^{N} |a_j|^2 \sum_{l=-\lfloor \frac{L-1}{D} \rfloor}^{\lfloor \frac{L-1}{D} \rfloor} \left| \left(g_i * h_j \right)[L-1+Dl] \right|^2. \end{aligned} \tag{9}$$

The likelihood ratio can be derived as

$$\begin{aligned} \Lambda(Y_i[k]) &= \frac{\mathcal{L}\left(X_i[k] = 1 \mid Y_i[k] \right)}{\mathcal{L}\left(X_i[k] = -1 \mid Y_i[k] \right)} = \frac{f_i\left[Y_i[k] | X_i[k] = 1 \right]}{f_i\left[Y_i[k] | X_i[k] = -1 \right]} \\ &= \exp\left(\frac{2a_i \left(g_i * h_i \right)[L-1]}{\left(\sigma_{I,i}^2 + \sigma_{N,i}^2 \right)} Y_i[k] \right) \end{aligned} \tag{10}$$

where $f_i(y|x)$ is the conditional probability density function (pdf) of $Y_i[k]$ given that $X_i[k] = x$ is transmitted. The simple form of likelihood ratio shown in (10) leads to a simple decision rule for the MLE, specifically,

$$\hat{X}_i^{(0)}[k] = \text{sgn}(Y_i[k]) = \begin{cases} +1, & \text{if } Y_i[k] \geqslant 0, \\ -1, & \text{if } Y_i[k] < 0. \end{cases} \tag{11}$$

In (11), the superscript "(0)" of $\hat{X}_i^{(0)}[k]$ indicates that the decision is made based on the output of the basic TRDMA scheme (without any interference cancellation).

The error probability of the estimator shown in (11) can be calculated based on the Gaussian approximations of the interference as follows

$$P_{err}^{(0)}(i) = Q\left(\sqrt{\frac{|a_i|^2 \sum_{l=0}^{L-1} |h_i[l]|^2}{\sigma_{I,i}^2 + \sigma_N^2}} \right) = Q\left(\sqrt{SINR_i^{(0)}} \right), \tag{12}$$

where $SINR_i^{(0)}$ is the Signal-to-Interference-plus-Noise Ratio (SINR) for User i achieved in the basic TRDMA scheme. From (12), one can see that the error probability decreases

[4]Unlike the *physical* spatial focusing effect observed in the downlink in which the useful signal power is concentrated at different physical locations, in the uplink, the signal power concentration in the users' signature waveform space is achieved mathematically at the BS.

[5]More rigorously, here $Y_i[k] = Y_i^{[D]}[L-1+Dk]$ which aligns the highest temporal focusing gain $(g_i * h_i)[L-1]$ in $Y_i[k]$ with the transmitted symbol $X_i[k]$ in time for ease of simple notation.

[6]because the interference term is a linear combination of the zero-mean binary symmetric symbols $X_i[k] \in \{+1, -1\}$.

with the achieved SINR, i.e. the quality of the signal before the final decision.

In the following sections, we discuss the 2D interference cancellation scheme which uses the estimated symbols to effectively cancel both the ISI and IUI, and significantly improves the performance.

III. 2-Dimensional Parallel Interference Cancellation

In this part, we describe the proposed 2D parallel interference cancellation scheme.

The TRDMA system is an interference-limited system, especially in the high signal-to-noise ratio (SNR) regime. Fortunately, unlike the random noise, the interference terms shown in (8) have their own structure, which can be explored to further improve the BER performances. Since the CIRs have been obtained at the BS during the channel probing phase[7], the interference terms in (8) can be reconstructed if the relevant transmitted symbols are known. In our interference cancellation scheme, the estimated symbols from the basic TRDMA system are used to approximate the interference terms. Unlike the existing multiuser detection scheme in CDMA systems, the interference cancellation of the TRDMA system is complicated by the fact that the interference consists of two parts belonging to two different dimensions: the ISI is due to the large delay spread in broadband communications, which is in the time domain; the IUI is caused by the simultaneous transmission of multiple users, which is in the user's signature domain. The proposed 2D parallel interference cancellation scheme for the TRDMA uplink system targets at the interference in both of the two dimensions, by exploiting the structure of interference in both dimensions.

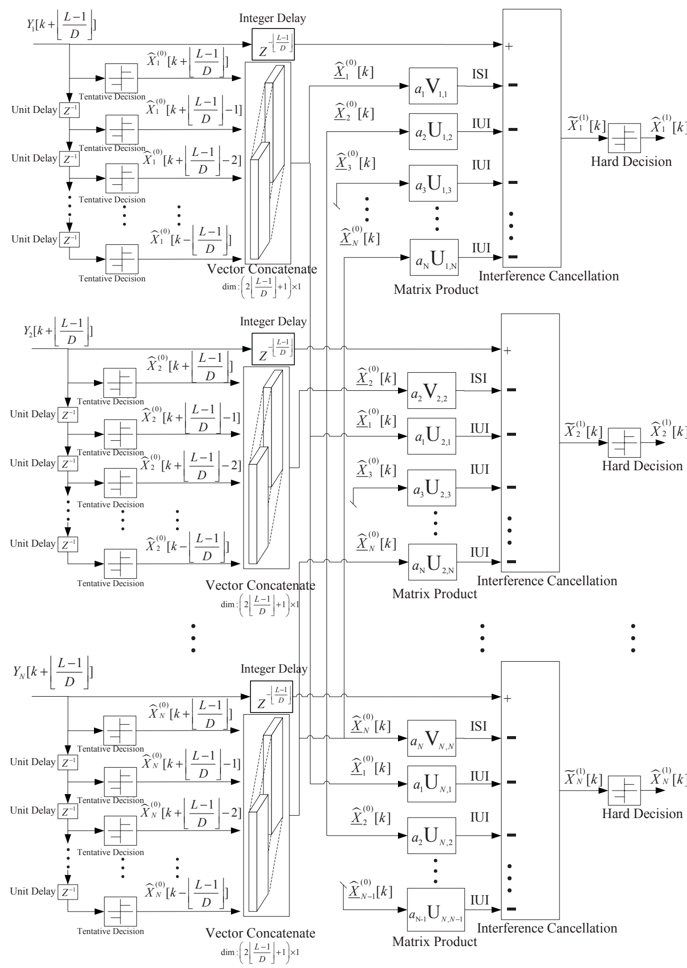

Fig. 2. The diagram of the 2-Dimensional Parallel Interference Cancellation.

A. Tentative Decision Vector

Due to the unique structure of TR waveform, each received symbol suffers the interference caused by those symbols transmitted before and after this symbol. According to (8), in order to ideally cancel the interference for User i's symbol $X_i[k]$, one has to know all the other users' transmitted symbols from time $\left(k - \lfloor\frac{L-1}{D}\rfloor\right)$ to $\left(k + \lfloor\frac{L-1}{D}\rfloor\right)$ for the IUI, and User i's own transmitted symbols from time $\left(k - \lfloor\frac{L-1}{D}\rfloor\right)$ to $(k-1)$ and from $(k+1)$ to $\left(k + \lfloor\frac{L-1}{D}\rfloor\right)$ for the ISI.

In reality, tentative decisions are made in attempt to estimate these symbols. To simplify the notation in the sequel, define the vector $\underline{\hat{X}}_j^{(0)}[k]$ for all $j \in \{1, 2, \ldots, N\}$, as the tentative decision vector for User j, as shown in (13).

Since the tentative decisions for User j solely depend on this user's own TRM output, the tentative decision vectors can be obtained in parallel for all the users in the propose 2D parallel interference cancellation scheme.

B. Approximated Interference Reconstruction

Based on the tentative decisions of the transmitted symbols, the approximated interference terms in (8) can be reconstructed by looking at the structure of the ISI and IUI. In doing so, we first define the row vector $\mathbf{U}_{i,j}$ for $\forall i, j \in \{1, 2, \ldots, N\}$ as shown in (14), so that the ISI canceler vector and the IUI canceler vector can be easily represented as follows:

- ISI Canceler Vector: Considering the ISI to $X_i[k]$ as a linear combination of User i's own symbols, define the ISI canceler vector $\mathbf{V}_{i,i}$ for User i to be

$$\mathbf{V}_{i,i} \triangleq \mathbf{U}_{i,i} \mathcal{D}\left(\underline{\mathbf{1}}, 0, \underline{\mathbf{1}}\right), \tag{15}$$

  where $\mathcal{D}(\underline{z})$ is a diagonal matrix whose diagonal elements are listed by $\underline{z}$, and $\underline{\mathbf{1}} \triangleq \{1, 1, \ldots, 1\}$ of length $\lfloor\frac{L-1}{D}\rfloor$. As a result, the approximated ISI term for User i's symbol $X_i[k]$ can be written in a compact form as the product of the ISI canceler vector $\mathbf{V}_{i,i}$ and the tentative decision vector $\underline{\hat{X}}_i^{(0)}[k]$ shown as follows

$$ISI = a_i \mathbf{V}_{i,i} \underline{\hat{X}}_i^{(0)}[k]. \tag{16}$$

- IUI Canceler Vector: Similarly, we define the IUI canceler vector for the IUI caused by User j to User i as $\mathbf{U}_{i,j}$, so that the estimated IUI term to be canceled for User i's symbol $X_i[k]$ can be obtained as

$$IUI = \sum_{\substack{j=1 \\ j \neq i}}^{N} a_j \mathbf{U}_{i,j} \underline{\hat{X}}_j^{(0)}[k]. \tag{17}$$

[7]Note that the coefficients $\{a_i\}$ are in fact determined by the BS and sent to users.

$$\underline{\hat{X}}_j^{(0)}[k] \triangleq \left[\hat{X}_j^{(0)}[k+\lfloor\frac{L-1}{D}\rfloor], \hat{X}_j^{(0)}[k+\lfloor\frac{L-1}{D}\rfloor-1], \ \ldots \ , \hat{X}_j^{(0)}[k-\lfloor\frac{L-1}{D}\rfloor]\right]^T$$
$$= \left[\mathrm{sgn}\left(Y_j[k+\lfloor\frac{L-1}{D}\rfloor]\right), \mathrm{sgn}\left(Y_j[k+\lfloor\frac{L-1}{D}\rfloor-1]\right), \ \ldots \ , \mathrm{sgn}\left(Y_j[k-\lfloor\frac{L-1}{D}\rfloor]\right)\right]^T. \quad (13)$$

$$\mathbf{U}_{i,j} \triangleq \left[(g_i * h_j)\left[L-1-D\lfloor\frac{L-1}{D}\rfloor\right], (g_i * h_j)\left[L-1-D\left(\lfloor\frac{L-1}{D}\rfloor-1\right)\right], \ldots \ , (g_i * h_j)\left[L-1+D\lfloor\frac{L-1}{D}\rfloor\right]\right], \quad (14)$$

C. 2D Interference Cancellation

The proposed 2D parallel interference cancellation scheme is shown in Fig. 2. From Fig. 2, one can see that the input signals for all the N users are first buffered by delay chains of length $2\lfloor\frac{L-1}{D}\rfloor$. Then tentative hard decisions are made in parallel for each user to obtain the vector $\underline{\hat{X}}_i^{(0)}[k]$ for $\forall i \in \{1, 2, \ldots, N\}$ using the decision rule (11). Upon obtaining the tentative decision vectors $\underline{\hat{X}}_i^{(0)}[k]$ for all $i \in \{1, 2, \ldots, N\}$, the interference terms are reconstructed and then subtracted from the signal $Y_i[k]$ with the ISI and IUI canceler vectors.

Similar to the definition in (13), denoting $\underline{X}_j[k]$ as (18), we can rewrite (8) in a more compact form as shown in (19).

After the interference cancellation, the resulting soft-bit $\tilde{X}_i^{(1)}[k]$ can be written as (20). A hard decision $\hat{X}_i^{(1)}[k] = \mathrm{sgn}\left(\tilde{X}_i^{(1)}[k]\right)$ can made based on $\tilde{X}_i^{(1)}[k]$ to achieved a more refined estimation for the transmitted symbol.

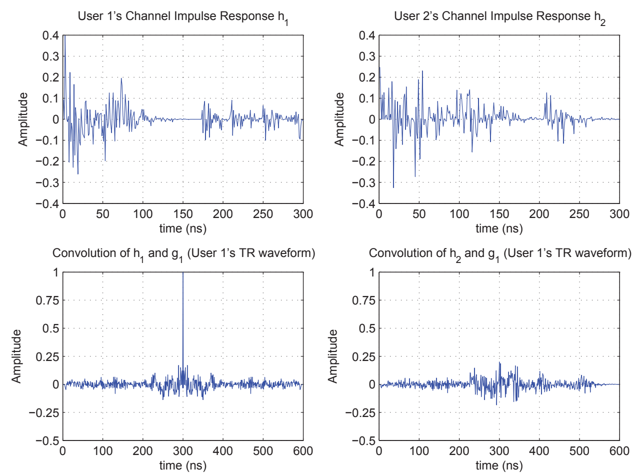

Fig. 3. Examples of IEEE 802.15.4a outdoor NLOS channels

IV. Simulation Results

In this section, we present some simulation results on the BER performance of the proposed 2D parallel interference cancellation scheme.

To study the proposed scheme in a more realistic setting, we used the more practical IEEE 802.15.4a outdoor non-line-of-sight (NLOS) channel model[8] [19] to evaluate the BER performance of the proposed scheme. Fig. 3 shows an example of two typical channel impulse responses under such a channel model and their convolutions with the TR signature waveforms. The channels shown in Fig. 3 are randomly generated according to the channel model specified in [19], with the system sampling period $T_s = 1$ ns and the channel length truncated[9] at $LT_s = 300$ ns (i.e., L=300). In Fig. 3, the convolution between User 1's CIR h_1 and its matched TR signature waveform g_1 exhibits a prominent central peak at $(h_1 * g_1)[L-1]$, demonstrating the temporal focusing effect of the TR technique; on the other hand, the amplitude of the convolution between the TR signature waveform g_1 and the mismatched CIR h_2 is significantly smaller than the central peak $(h_1 * g_1)[L-1]$, demonstrating the equivalent spatial focusing effect in the user's signature domain.

In the simulation, the CIRs for different users are randomly and independently generated using the IEEE 802.15.4a channel model, with $T_s = 1$ ns and $L = 300$. Without loss of generality, the CIR of each user is normalized so that $\sum_{k=0}^{L-1} |h_i[k]|^2 = 1, \quad \forall i \in \{1, 2, \ldots, N\}$, and assume that all the power control coefficients $a_i = 1, \quad \forall i \in \{1, 2, \ldots, N\}$[10]. A large number of independent trials of channel realizations were conducted and averaged to characterize the average performance of the proposed scheme under this channel model.

The BER performance versus E_b/N_0 (the energy-per-bit to noise-power-spectral-density ratio) is shown in Fig. 4 and Fig. 5 with various combinations of rate back-off factor D and the total number of users N. The energy-per-bit E_b is normalized to 1 by the assumption that each BPSK symbol $X_i[k] \in \{-1, +1\}$ has a unit power; accordingly, the power of the received AWGN $\tilde{n}[k]$ at the BS is then given by

$$\sigma_N^2 = \frac{N_0}{2} = \left(\frac{2E_b}{N_0}\right)^{-1}.$$

Fig. 4 considers that case where there are $N = 5$ end-users accessing the BS at the same time with a rate back-off factor $D = 16$ (about 5.3% of the channel length $L = 300$); Fig. 5 then presents the BER performance with $N = 10$ and $D = 32$ (about 10.7% of the channel length). As one can see in both figures, significant BER performance gain is achieved by the proposed 2D parallel interference cancellation scheme, compared with the basic TRDMA system without interference

[8]In such a channel model, each channel tap is a real number.

[9]because the amplitude of the remaining paths after 300 ns is typically small enough to be neglected

[10]To implement an equal power allocation among the users.

$$\underline{X}_j[k] \triangleq \left[X_j[k+\lfloor\frac{L-1}{D}\rfloor], X_j[k+\lfloor\frac{L-1}{D}\rfloor-1], \ \ldots \ , X_j[k-\lfloor\frac{L-1}{D}\rfloor]\right]^T, \tag{18}$$

$$Y_i[k] = a_i\sqrt{\sum_{l=0}^{L-1}|h_i[l]|^2}X_i[k] + a_i\mathbf{V}_{i,i}\underline{X}_i[k] + \sum_{\substack{j=1\\j\neq i}}^{N} a_j\mathbf{U}_{i,j}\underline{X}_j[k] + n_i[k]. \tag{19}$$

$$\tilde{X}_i^{(1)}[k] = a_i\sqrt{\sum_{l=0}^{L-1}|h_i[l]|^2}X_i[k] + a_i\mathbf{V}_{i,i}\left(\underline{X}_i[k]-\underline{\hat{X}}_i^{(0)}[k]\right) + \sum_{\substack{j=1\\j\neq i}}^{N} a_j\mathbf{U}_{i,j}\left(\underline{X}_j[k]-\underline{\hat{X}}_j^{(0)}[k]\right) + n[k]. \tag{20}$$

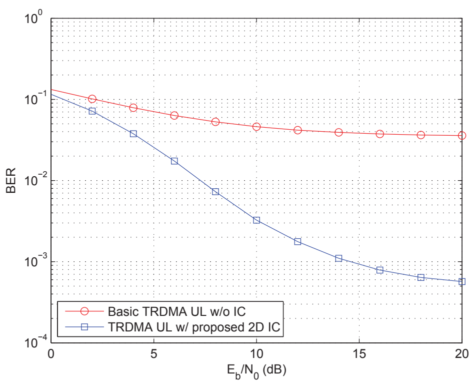

Fig. 4. The BER performance of the D=16 N=5

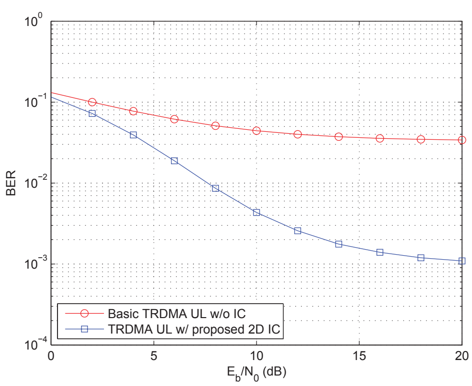

Fig. 5. The BER performance of the D=32 N=10

cancellation, which demonstrates the advantage and practical effectiveness of the proposed scheme.

V. Conclusion

In this paper, we introduced a multi-user TRDMA uplink architecture and proposed a 2D parallel interference cancellation scheme to enhance the system performance. As we discussed in this paper, such a TRDMA uplink architecture keeps the cost of end-users at a minimum level, and reuses the processing power at the base station (BS) that has already been made available for the downlink. The proposed 2D parallel interference cancellation scheme utilizes the tentative decisions of detected symbols to effectively cancel the interference in both the time dimension (ISI) and the user dimension (IUI). The performance results demonstrated that the proposed 2D parallel interference cancellation scheme can significantly improve the system performance of the TRDMA system.

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