SGD Frequency-Domain Space-Frequency Semiblind Multiuser Receiver with an Adaptive Optimal Mixing Parameter

Samphan PHROMPICHAI

Dept. of Electronic Engineering, Mahanakorn University of Technology, Bangkok 10530, Thailand

samphan@mut.ac.th

Abstract. *A novel stochastic gradient descent frequency-domain (FD) space-frequency (SF) semiblind multiuser receiver with an adaptive optimal mixing parameter is proposed to improve performance of FD semiblind multiuser receivers with a fixed mixing parameters and reduces computational complexity of suboptimal FD semiblind multiuser receivers in SFBC downlink MIMO MC-CDMA systems where various numbers of users exist. The receiver exploits an adaptive mixing parameter to mix information ratio between the training-based mode and the blind-based mode. Analytical results prove that the optimal mixing parameter value relies on power and number of active loaded users existing in the system. Computer simulation results show that when the mixing parameter is adapted closely to the optimal mixing parameter value, the performance of the receiver outperforms existing FD SF adaptive step-size (AS) LMS semiblind based with a fixed mixing parameter and conventional FD SF AS-LMS training-based multiuser receivers in the MSE, SER and signal to interference plus noise ratio in both static and dynamic environments.*

Keywords

SGD, semiblind, SFBC, MIMO, MC-CDMA, Adaptive Step-size.

1. Introduction

Very high data transmission rate is expected with strong demand by the next generation broadband multimedia wireless communication standards. In high data rate transmission scenarios, direct sequence code division multiple access (DS-CDMA) techniques are considered as the preferred multiple access strategy in previous mobile communication systems [1-2]. Due to multiple propagation paths, there always exist both multiple access interference (MAI) and intersymbol interference (ISI). Both MAI and ISI limit the capacity of DS-CDMA systems.

Recently, multicarrier transmission schemes such as orthogonal frequency division multiplexing (OFDM) and multi-carrier code division multiple access (MC-CDMA) are promising techniques for overcoming the relative capacity limitation of DS-CDMA [3]. Each multicarrier transmission scheme has both advantages and disadvantages in comparison with the others [4].

MC-CDMA system represents itself as a multiplexing technique which combines DS-CDMA with an efficient fast Fourier transform (FFT) technique passing OFDM. It exploits the frequency-domain (FD) spreading code instead of the time-domain (TD) spreading code, and spreads the multiuser data signal in narrow band. Hence, it possesses advantages such as having nearly optimal multipath diversity, robustness to ISI, better utilizes the spectrum and meets the demand of mobile multimedia services. As appeared in [3], [5], MC-CDMA is instrumental in improving the performance of mobile systems in fast time varying fading environments.

To combat ISI, a cyclic prefix (CP) of adequate length is inserted in the transmit sequence of MC-CDMA block signal. If the channel is time-invariant within a block, ISI and intercarrier interference (ICI) existence due to the multipath channel are effectively canceled. This simplifies the receiver hardware implementations, since the equalizer is just a one-tap FD filter. Nevertheless, the next generation of wireless systems will operate at high transmit frequency, high data rate, and high level of mobility, resulting in a multipath channel whose lengths are possibly longer than the CP. As a consequence, channel variations over block destroying the orthogonality among subcarriers cannot be avoided. This leads to ISI, ICI, multiuser interference (MUI) and receiver's performance degradation [6], [7].

Application of the space-time block code (STBC) [8] to the downlink of wireless communication systems provides maximum diversity gains and combats fading channel in the wireless link. Through the use of multiple antennas, transmit diversity gain and coding gain can be exploited without additional power and bandwidth. Many research efforts integrate the STBC into various multiple access schemes to combat the impairments of the wireless multiuser channels [9-11]. A space-frequency block coding (SFBC) based on STBC Alamouti's scheme was proposed in [12]. This technique offers space and frequency diversity over multi-antenna and frequency-selective fading channels. As appeared in [12], [13], the SFBC using code division multiplexing (CDM) in OFDM system has better performance and is more robust than STBC OFDM system.

Blind multiuser detection and channel estimation receivers based on subspace decomposition are proposed in [14-16]. Blind receivers appear more attractive than the non-blind counterpart, i.e. the training-based ones since the bandwidth and power are not consumed by the training signals. However, the blind algorithms require a long duration of observation and often result in a phase ambiguity in the estimate. Moreover, the channel is required to be time invariant during a long period. For STBC based on Alamouti's scheme [8] in frequency-selective fading channel, it is impossible to achieve blind receiver due to implicit ambiguity [9]. Therefore, in practice of the blind algorithms for very high data rate future mobile wireless communication systems are limited unless these drawbacks are alleviated.

The pilot (training) signal and multiuser signal are together transmitted in parallel, which is called the common pilot channel (CPICH) as a standard for 3rd Generation Partnership Project 2 (3GPP2) mobile communication systems [17]. This technique is very beneficial for the multiuser receiver to track fast time-varying multipath channel information in order to detect the desired user data and suppress interferences.

Recently, the semiblind receiver has been gaining interest for high data rate mobile wireless communication systems. The criterion of a semiblind receiver combines information of both known (pilot) and unknown (estimating) data signals for tracking channel and suppressing ISI. It has been proven in [18], [19], that this technique provides superior performance over blind or pilot-based ones. An optimal linear semiblind receiver in the form of minimum mean square error (MMSE) [20] and the semiblind channel estimation using the exact maximum-likelihood estimate receiver [21] were proposed for downlink systems. These techniques achieve a reasonable trade-off between performance and typically prohibitive large complexity. A suboptimal semiblind space-frequency (SF) multiuser detection [22], semiblind channel estimation [23], and semiblind multiuser receiver [11] presented a method based on subspace decomposition. These schemes are batch-processing and employed in scenarios where the pilot and unknown data do not overlap in time.

Frequency domain equalizer (FDE) has been shown to be an attractive scheme for wireless systems with frequency-selective fading channel. Compared with the time-domain equalizer (TDE), FDE has less computational complexity and better convergence property [24]. The linear FD channel estimation for multiple-input multiple-output (MIMO) downlink systems based on least square (LS) and MMSE criteria were proposed in [25-28]. The FD multiuser receivers [29], [30] were proposed for MIMO-CDMA systems with CPICH in frequency selective-fading channel. The FD semiblind channel estimation using data energy besides pilot signal energy was proposed for 3GPP LTE uplink systems [31]. These schemes can be operated in the maximum multi-antenna diversity, maximum multipath diversity and multiuser communication scheme. In addition, the receivers are designed to act on each per-tone basis in FD and require the estimation from the inverse matrices. Therefore, the overall computational complexity increases relatively with number of used frequency tones in the systems and the length of filter weight vector.

Least-mean-square (LMS) type adaptive receivers are attractive due to their very low computational complexity. The fast convergence FD training-based LMS adaptive multiuser receiver for STBC MC-CDMA systems was proposed in [32]. The updated weight vector relies on the relationship between two mean-square errors (MSE) from odd and even indexes. The FD LMS adaptive decision feedback equalizer [33] and the variable step-size based LMS channel estimation algorithm [34] were proposed for single carrier systems. However, these methodologies are designed to operate on systems with sufficient CP and have not been applied with CPICH systems. Moreover, these techniques suffer from the problem of signal to interference plus noise ratio (SINR) drop resulting from the use of a shared equalizer in the detection of the desired user data.

In this paper, we propose a novel methodology to improve the performance of FD semiblind multiuser receivers with a fixed mixing parameter by using an adaptive optimal mixing parameter. The mixing parameter plays a key role to control the mixing information ratio between blind-based and training-based modes with various amounts of active loaded users existing in the systems.

The contributions of this paper are as follows: First, a mathematical framework of a synchronous SFBC down link MIMO MC-CDMA with CPICH and without CP signal model is presented, and matrix for using the advantage of diversity from SF technique and array antennas is for-

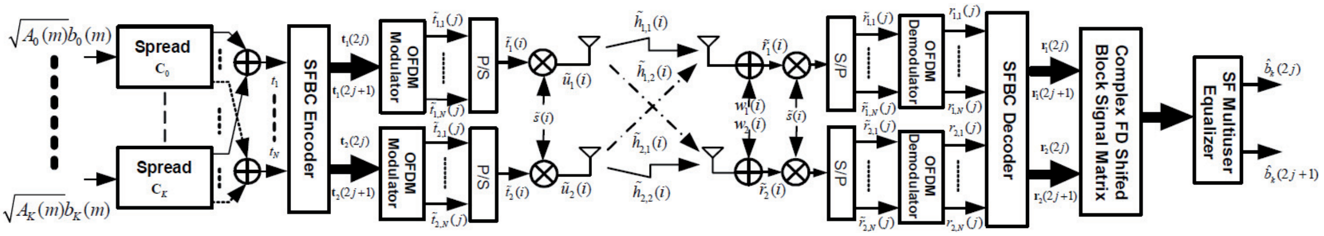


Fig. 1. The SFBC Downlink MIMO MC-CDMA with CPICH and without CP scheme.

mulated. Second, the suboptimal FD SF semiblind multiuser receiver with mixing parameter is considered. The optimal mixing parameter is analytically addressed. Third, to reduce computational complexity, the stochastic gradient descent (SGD) FD SF semiblind multiuser receiver with adaptive parameters is proposed.

Computer simulation results show that the proposed semiblind receiver outperforms existing adaptive step-size (AS) LMS semiblind with fixed mixing parameter and conventional AS-LMS training-based multiuser receivers in MSE, symbol error rate (SER) and SINR in both static and dynamic channel models.

1.1 Notation

In this paper, we use bold lower case for vectors and bold upper case for matrices. Also, $*$ is convolution operation, $(\cdot)^T$ for transpose, $(\cdot)^H$ for Hermitian matrix, $(\cdot)^*$ for complex conjugate, $(\cdot)^\dagger$ for inverse matrix and $\lceil \bullet \rceil$ denotes rounding up to the nearest integer. Throughout this paper, receiver, equalizer and algorithm convey the same meaning and are used interchangeably.

2. SFBC Downlink MIMO MC-CDMA with CPICH System

Let us consider a baseband model for SFBC downlink MIMO MC-CDMA with CPICH and without CP system which is illustrated in Fig. 1. For conciseness, we will focus on a base station (BS) with two transmit antennas and a mobile with two receive antennas, where the base station has K symbol-synchronous active users existing in the systems. The k^{th} mobile user is assigned an orthogonal FD spreading code of length N, with user $k = 0$ reserved for the pilot signal. Following this, the signals from all users, including the pilot, are combined. Hence, a synchronous code division multiplexed signal $\mathbf{t}(m)$ is given by

$$\mathbf{t}(m) = \mathbf{C}\mathbf{x}(m) \tag{1}$$

where $\mathbf{x}(m) = [\sqrt{A_0(m)}b_0(m),\ldots,\sqrt{A_K(m)}b_K(m)]^T$, $A_k(m)$ and $b_k(m)$ are power and data symbol for k^{th} user, m is symbol sequence, $\mathbf{C} = [\mathbf{c}_0,\ldots,\mathbf{c}_K]$ and $\mathbf{c}_k = [c_{k,0},\ldots,c_{k,N-1}]^T$ are complex spreading code matrix and vector, respectively. The complex transmit multiuser signal $\mathbf{t}(m)$ is stored for two symbols (data block) and loaded into the SFBC encoder for using the diversity from SF and MIMO techniques which is based on the STBC Alamouti's scheme [8], [12]

$$\begin{bmatrix} \mathbf{t}_1(2j) & \mathbf{t}_1(2j+1) \\ \mathbf{t}_2(2j) & \mathbf{t}_2(2j+1) \end{bmatrix} \tag{2}$$

where

$$\mathbf{t}_1(2j) = \left[t(2(j-1)N),\ldots,t(2(j-1)N+N-1)\right],$$

$$\mathbf{t}_2(2j) = \left[t(2(j-1)N+N),\ldots,t(2(j-1)N+2N-1)\right], \tag{3}$$

and

$$\mathbf{t}_1(2j+1) = -\mathbf{t}_2^*(2j)\mathbf{P}_N,$$

$$\mathbf{t}_2(2j+1) = \mathbf{t}_1^*(2j)\mathbf{P}_N. \tag{4}$$

where j is block sequence and $\mathbf{P}_N$ is an $N \times N$ permutation matrix that performs a reversal of the entries. The complex transmit multiuser signals, even $\mathbf{t}_{M_T}(2j)$ and odd $\mathbf{t}_{M_T}(2j+1)$ block signal sequences, are loaded into the OFDM modulators using the inverse discrete Fourier transform (IDFT). It is assumed that the number of subcarriers is equal to the processing gain of the spreading code.

$$\begin{aligned} \tilde{\mathbf{t}}_{M_T}(j) &= \mathrm{IDFT}\left(\mathbf{t}_{M_T}(j)\right), \\ &= \left[\tilde{t}_{M_T}(0),\ldots,\tilde{t}_{M_T}(N-1)\right]. \end{aligned} \tag{5}$$

where $M_T = 1, 2$ is the index of the transmit antenna. After modulation, the complex FD transmit multiuser encoding signal $\mathbf{t}_{M_T}(j)$ is transformed to the complex TD transmit multiuser encoding signal $\tilde{\mathbf{t}}_{M_T}(j)$. Finally, the complex TD encoding multiuser block signal both even $\tilde{\mathbf{t}}_{M_T}(2j)$ and odd $\tilde{\mathbf{t}}_{M_T}(2j+1)$ sequences are loaded into parallel-to-series converter, multiplied by a cell-specific long scrambling code sequence $\tilde{s}(i)$ and transmit at the M_T^{th} transmit antenna

$$\tilde{u}_{M_T}(i) = \tilde{t}_{M_T}(i) \times \tilde{s}(i) \tag{6}$$

where i is chip rate index. The signal from BS propagates through MIMO multipath frequency-selective fading channel. Here, the channel is modeled as a finite impulse response (FIR) filter with complex channel impulse response $\tilde{\mathbf{h}}_{M_T,M_R}(l), l \in \{0,\ldots,L_h\}$, where L_h is order of channel. The received signal at the mobile station (MS) antenna is then the convolutional result of transmit signal and MIMO channel impulse response plus corrupted additive white Gaussian noise (AWGN), i.e.

$$\tilde{r}_{M_{R=1}}(i) = \tilde{u}_1(i) * \tilde{h}_{1,1}(i) + \tilde{u}_2(i) * \tilde{h}_{2,1}(i) + \tilde{w}_1(i),$$

$$\tilde{r}_{M_{R=2}}(i) = \tilde{u}_1(i) * \tilde{h}_{1,2}(i) + \tilde{u}_2(i) * \tilde{h}_{2,2}(i) + \tilde{w}_2(i) \tag{7}$$

where $\tilde{w}_{M_R}(i)$ is complex AWGN with mean 0 and variance σ_w^2, and $M_R = 1, 2$ is the index of the receive antenna.

At the receiver, the complex TD received multiuser chip signal sequence $\tilde{r}_{M_R}(i)$ is descrambled by the cell-specific long scrambling code $\tilde{s}(i)$, then stored for two symbols, transformed information to FD using OFDM demodulators and loaded into SFBC decoder. To obtain the advantage of diversity from SFBC technique and array antennas, the $L_f \times N$ complex FD received multiuser shifted block signal sequence matrix $\mathbf{R}(j)$ is compactly formulated as

$$\mathbf{R}(j) = \mathrm{F}_N\left(\left(\tilde{\mathbf{H}}\tilde{\mathbf{T}}(j) + \tilde{\mathbf{W}}(j)\right)^H\right),$$

$$\mathbf{R}(j)=\begin{bmatrix} r_1\left(2(j-1)N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)\right) & \cdots & r_1\left(2(j-1)N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)+N-1\right) \\ r_2\left(2(j-1)N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)\right) & & r_2\left(2(j-1)N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)+N-1\right) \\ \vdots & \vdots & \vdots \\ r_1\left(2(j-1)N\right) & \cdots & r_1\left(2(j-1)N+N-1\right) \\ r_2\left(2(j-1)N\right) & & r_2(2(j-1)N+N-1) \\ r_1\left(2(j-1)N+N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)\right) & \cdots & r_1\left(2(j-1)N+N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)+N-1\right) \\ r_2\left(2(j-1)N+N-\left(\left\lceil\frac{L_f}{4}\right\rceil\right)\right) & & r_1(2(j-1)N-\left\lceil\frac{L_f}{4}\right\rceil+N-1) \\ \vdots & \vdots & \vdots \\ r_1\left(2(j-1)N+N\right) & \cdots & r_1(2(j-1)N+N+N-1) \\ r_2\left(2(j-1)N+N\right) & & r_2(2(j-1)N+N+N-1) \end{bmatrix} \tag{8}$$

where F_N is a sliding FFT [35], **W** is an AWGN matrix and

$$\tilde{\mathbf{H}}(j)=\begin{bmatrix} \tilde{\mathbf{H}}_1(j) & \tilde{\mathbf{H}}_2(j) \\ \tilde{\mathbf{H}}_2^*(j)\mathbf{P}_{(L_h+1)+\left(\left\lceil\frac{L_f}{2}\right\rceil\right)} & -\tilde{\mathbf{H}}_1^*(j)\mathbf{P}_{(L_h+1)+\left(\left\lceil\frac{L_f}{2}\right\rceil\right)} \end{bmatrix}, \tag{9}$$

where

$$\tilde{\mathbf{H}}_{M_T}(j)=\begin{bmatrix} \tilde{\mathbf{h}}_{M_T}(L_h) & \cdots & \tilde{\mathbf{h}}_{M_T}(0) & \mathbf{0}_{2\times1} & \cdots & \mathbf{0}_{2\times1} \\ \mathbf{0}_{2\times1} & \tilde{\mathbf{h}}_{M_T}(L_h) & \cdots & \tilde{\mathbf{h}}_{M_T}(0) & \cdots & \mathbf{0}_{2\times1} \\ \vdots & \vdots & \ddots & & \ddots & \vdots \\ \mathbf{0}_{2\times1} & \mathbf{0}_{2\times1} & \cdots & \tilde{\mathbf{h}}_{M_T}(L_h) & \cdots & \tilde{\mathbf{h}}_{M_T}(0) \end{bmatrix} \tag{10}$$

where

$$\tilde{\mathbf{h}}_{M_T=1}(l)=\left[\tilde{h}_{1,M_R=1}(l),\ldots,\tilde{h}_{1,M_R=2}(l)\right]^T,$$

$$\tilde{\mathbf{h}}_{M_T=2}(l)=\left[\tilde{h}_{2,M_R=1}(l),\ldots,\tilde{h}_{2,M_R=2}(l)\right]^T, \tag{11}$$

and

$$\tilde{\mathbf{T}}(j)=\begin{bmatrix} \tilde{\mathbf{T}}_1(2j) \\ \tilde{\mathbf{T}}_2(2j) \end{bmatrix} \tag{12}$$

where

$$\tilde{\mathbf{T}}_{M_T}(j)=\begin{bmatrix} \tilde{t}_{M_T}\left(2jN-\left(L_h+\left\lceil\frac{L_f}{2}\right\rceil+1\right)\right) & \cdots & \tilde{t}_{M_T}\left(2jN-\left(L_h+\left\lceil\frac{L_f}{2}\right\rceil+1\right)+N-1\right) \\ \vdots & \vdots & \vdots \\ \tilde{t}_{M_T}(2jN) & \cdots & \tilde{t}_{M_T}(2jN+N-1) \end{bmatrix} \tag{13}$$

and L_f denotes length of the equalizer which is selected.

3. FD SF Multiuser Receivers

In this section, a theoretical FD SF multiuser-trained MMSE receiver is presented. A suboptimal FD SF semiblind multiuser receiver with mixing parameter is considered, and the solution obtained optimal mixing parameter is derived. Finally, an SGD FD SF semiblind multiuser receiver with adaptive parameters is proposed to reduce the computational complexity.

3.1 FD SF Multiuser-trained MMSE Receiver

A theoretical FD SF multiuser-trained MMSE equalizer obtained by minimizing the MSE criterion is considered. The advantage of diversity from SFBC technique and array antennas passing the complex FD received multiuser shifted block signal sequence matrix **R**(*j*) are used to update algorithms. For conciseness, FD SF multiuser-trained MMSE cost function in odd and even parts are formulated as

$$J(\mathbf{f}_{\mathrm{MMSE}})=\mathrm{E}\left\{\left|\mathbf{f}_{\mathrm{MMSE}}^H(j)\mathbf{R}(j)-\mathbf{t}_v(j)\right|^2\right\} \tag{14}$$

where $\mathbf{t}_\mathbf{v}=[0,\ldots,0,t_v,0,\ldots0]$ is complex synchronous FD SF multiuser training signal for subcarrier *v*.

For supporting (14), we assume that the receiver knows the complex synchronous FD SF multiuser training signal **t**(*j*). It is an independent and identically distributed (i.i.d.) random variable with zero mean and unit variance. Hence, the updated equation of FD SF multiuser-trained MMSE equalizer is given as (see Appendix A.)

$$\mathbf{f}_{\mathrm{MMSE}}=\frac{\sigma_t^2}{N}\left(\sigma_t^2\mathbf{H}\mathbf{H}^H+\sigma_w^2\mathbf{I}\right)^\dagger\mathbf{H}\mathbf{i}_v \tag{15}$$

where $\mathbf{i}_\mathbf{v}=[0,\ldots,0,\underbrace{1}_{v},0,\ldots,0]$ is unit vector with one in *v* position, σ_w^2 noise power and σ_t^2 denotes total received signal power with *K* active loaded users existing in the systems.

$$\sigma_t^2=A_0+\sum_{k=1}^{K}A_k\,. \tag{16}$$

To obtain the updated optimal tap-weight equalizer, the receiver requires to perfectly know the complex FD channel response, total received signal power and noise power.

3.2 FD SF Semiblind Multiuser Receiver with Mixing Parameter

In practical use, transmission complex synchronous FD SF multiuser training signal **t**(*j*) obtained $\mathrm{f}_{\mathrm{MMSE}}$ wastes bandwidth and power efficiencies, and increases the system's complexity. Blind multiuser receivers are impractical for multipath frequency-selective fading channel. Moreover, blind and training-based receivers suffer from degraded performance in fast time varying fading channel compared to semiblind receivers. Therefore, the algorithm uses the advantage of transmit pilot signal parallel with data signals channel [17] is considered in this subsection. The suboptimal FD SF semiblind multiuser receiver with optimal mixing parameter is considered to improve the performance of FD semiblind multiuser receiver with fixed mixing parameters, which reduces the computational complexity of optimal linear FD semiblind receivers and optimal FD SF multiuser-trained MMSE receiver. The algorithm exploits the methodology of adapted mixing information ratio between training-based mode and blind-based mode.

To formulate the suboptimal algorithm, MSE cost function consisting of the blind-based and the training-based (non-blind) parts is given as

$$J(\mathbf{f},\phi)=\mathrm{E}\left\{\phi\left|e_d(j)\right|^2_{\text{blind}}+\left(1-\phi\right)\left|e_p(j)\right|^2_{\text{training-based}}\right\} \quad (17)$$

where

$$e_d(j)=\left(\mathbf{f}^H\boldsymbol{\gamma}_d-\hat{b}_d(j)\right)\ ,$$

$$e_p(j)=\left(\mathbf{f}^H\boldsymbol{\gamma}_p-b_p(j)\right) \quad (18)$$

where $\boldsymbol{\gamma}_d=\mathbf{R}(j)\mathbf{c}_d$, $\boldsymbol{\gamma}_p=\mathbf{R}(j)\mathbf{c}_p$, ϕ is a mixing parameter, $b_p(j)$ pilot data symbol block sequence, $\hat{b}_d(j)$ estimated data symbol block sequence of the desired user $\left(\hat{b}_d(j)=\left(\mathbf{f}^H(j)\boldsymbol{\gamma}_d\right)\right)$, $\mathbf{c}_d$ complex FD desired user spreading code vector and $\mathbf{c}_p$ is complex FD pilot spreading code vector.

For supporting the operation in very high data rate downlink MIMO MC-CDMA systems with multipath frequency-selective fading channel in which amplitude, phase and tapped delay of channel are varied with time. Moreover, tapped delay of channel is large delay spread over symbol block. Therefore, information from all subcarriers (1,…,*G*) or group are used to update the tap-weight coefficients vector of the equalizer passing the formulated complex FD received multiuser shifted block signal sequence matrix **R**(*j*). As a result, the suboptimal algorithm can be operated in either system with sufficient CP, insufficient CP or even without CP.

Assuming that the suboptimal receiver perfectly knows the complex FD desired user code $\mathbf{c}_d$ and pilot code $\mathbf{c}_p$ vectors. Hence, the updated equation of FD SF semiblind multiuser equalizer with mixing parameter is obtained as (see Appendix B.)

$$\mathbf{f}=\left(A_p-\phi\left(A_p+A_d\right)\right)\left(\sigma_t^2\mathbf{HH}^H+\sigma_w^2\mathbf{I}\right)^{\dagger}\mathbf{Hi}_v\,. \quad (19)$$

3.3 Optimal Mixing Parameter

Considering (17), performance of the suboptimal semiblind multiuser receiver relies upon the mixing parameter ϕ. Hence, the methodology obtained the optimal mixing parameter which is based on the following assumption:

- If mixing parameter ϕ is appropriately chosen, our FD SF semiblind multiuser with mixing parameter equalizer coincides with the theoretical FD SF multiuser-trained MMSE equalizer.

Since, the optimal mixing parameter is verified by setting (19) equal (15), i.e. **f**=**f**$_{\text{MMSE}}$

$$\begin{aligned}&\frac{\sigma_t^2}{N}\left(\sigma_t^2\mathbf{HH}^H+\sigma_w^2\mathbf{I}\right)^{\dagger}\mathbf{Hi}_v\\&=\left(A_p-\phi\left(A_p+A_d\right)\right)\left(\sigma_t^2\mathbf{HH}^H+\sigma_w^2\mathbf{I}\right)^{\dagger}\mathbf{Hi}_v\end{aligned}\ . \quad (20)$$

The suboptimal FD SF semiblind multiuser receiver with mixing parameter coincides with the FD SF multiuser-trained MMSE receiver, if and only if

$$A_p-\phi\left(A_p+A_d\right)=\frac{\sigma_t^2}{N} \quad (21)$$

hence, the optimal mixing parameter ϕ_{opt} is finally obtained as

$$\phi_{\text{opt}}=\frac{\left(A_p-\dfrac{\sigma_t^2}{N}\right)}{\left(A_p+A_d\right)} \quad (22)$$

where A_d is the received desire user power and A_p is the received pilot power, respectively.

From (22), we found that the optimal mixing parameter relies upon the power of each user and the number of active loaded users existing in the systems.

3.4 SGD FD SF Semiblind Multiuser Receiver with Adaptive Optimal Mixing Parameters

The SGD FD SF semiblind multiuser receiver based on the methodology of adaptive optimal parameters is proposed to improve performance of the FD semiblind multiuser receivers with fixed mixing parameter, and reduce the computational complexity of suboptimal FD semiblind multiuser receivers and suboptimal FD SF semiblind multiuser receiver with mixing parameter. Moreover, it increases the ability in tracking fast time varying multipath frequency-selective fading channel in SFBC downlink MIMO MC-CDMA with CPICH and without CP systems.

Applying a standard SGD method into (17), the adaptation for SGD FD SF semiblind multiuser equalizer tap-weight coefficients vector **f**(*j*) at *j*th even and odd block sequence using LMS algorithm is obtained as

$$\mathbf{f}(j+1)=\mathbf{f}(j)-\mu(j)\begin{pmatrix}\phi(j)e_d(j)\boldsymbol{\gamma}_d\\+\left(1-\phi(j)\right)e_p\boldsymbol{\gamma}_p\end{pmatrix}. \quad (23)$$

The SGD FD SF equalizer is employed to counter the effective multipath frequency-selective fading channels, restore the orthogonality of the user's spreading code signal and suppress MUI. However, performance of the SGD FD SF equalizer heavily depends on mixing parameter and a choice of step-size. Hence, the adaptive mixing parameter and the adaptive step-size [36] are incorporated in the semiblind updated function.

Referring to (22), to obtain the optimal mixing information ratio between the blind-based mode and the training-based mode, the receiver requires knowledge of the received signal power of pilot and desired user, and active loaded users existing in the systems which increase the computational complexity of the receiver. Hence, the automatically adaptive optimal mixing parameter using LMS algorithm is proposed. The adaptive mixing parameter at each recursion j, $\phi(j)$ is updated in order to minimize the $J(\mathbf{f},\phi)$ with respect to ϕ, $\left.\frac{\partial J(\mathbf{f},\phi)}{\partial \phi}\right|_{\phi=\phi(j)}$

$$\phi(j+1)=\left[\phi(j)-\beta\begin{pmatrix} e_d(j)e_d(j)-e_p(j)e_p(j) \\ +\begin{pmatrix} \phi(j)e_d(j)\boldsymbol{\gamma}_d \\ -\phi(j)e_p(j)\boldsymbol{\gamma}_p \\ +e_p(j)\boldsymbol{\gamma}_p \end{pmatrix}^H \Psi(j) \end{pmatrix}\right]_{\phi-}^{\phi+} \tag{24}$$

where β denotes as an adaptation parameter for the adaptive mixing parameter part and $[\bullet]_{\phi-}^{\phi+}$ is truncation to the lower and upper mixing parameter limits. The derivative $\Psi(j)$ representing $\left.\frac{\partial \mathbf{f}}{\partial \phi}\right|_{\phi=\phi(j)}$ is updated as

$$\begin{aligned}\Psi(j+1)=&\left(\mathbf{I}+\mu(j)\begin{pmatrix} \phi(j)\boldsymbol{\chi}_d \\ +\phi(j)\boldsymbol{\chi}_p+\boldsymbol{\chi}_p \end{pmatrix}\right)\Psi(j) \\ &-\mu(j)\big(e_d(j)\boldsymbol{\gamma}_d-e_p(j)\boldsymbol{\gamma}_p\big)\end{aligned} \tag{25}$$

where $\boldsymbol{\chi}_d=\boldsymbol{\gamma}_d\boldsymbol{\gamma}_d^H$ and $\boldsymbol{\chi}_p=\boldsymbol{\gamma}_p\boldsymbol{\gamma}_p^H$.

However, the performance of the SGD FD SF semiblind multiuser receiver is heavily dependent on the choice of step-size. Hence, the AS-LMS algorithm is incorporated which in turn improves the performance of the receiver in a dynamic channel where the number of interference users in the system is time-varying. The receiver automatically adapts the step-size by minimizing the mean square error output. Subsequently, the AS- LMS scheme at each recursion j, $\mu(j)$ is updated using the gradient obtained by minimizing the MSE cost $J(\mathbf{f},\phi)$ with respect to the step-size μ, $\left.\frac{\partial J(\mathbf{f},\phi)}{\partial \mu}\right|_{\mu=\mu(j)}$

$$\mu(j+1)=\left[\mu(j)-\alpha\begin{pmatrix} \phi(j)e_d(j)\boldsymbol{\gamma}_d \\ +\big(1-\phi(j)\big)e_p(j)\boldsymbol{\gamma}_p \end{pmatrix}^H \mathbf{q}(j)\right]_{\mu-}^{\mu+} \tag{26}$$

where α denotes as an adaptation parameter for the AS part and $[\bullet]_{\mu-}^{\mu+}$ is the truncation to the lower and upper step-size limits. The derivative $\mathbf{q}(j+1)$ represents $\left.\frac{\partial \mathbf{f}}{\partial \mu}\right|_{\mu=\mu(j)}$ and is adapted according to

$$\begin{aligned}\mathbf{q}(j+1)=&\left(\mathbf{I}-\mu(j)\begin{pmatrix} \phi(j)\boldsymbol{\chi}_d \\ +\big(1-\phi(j)\big)\boldsymbol{\chi}_p \end{pmatrix}\right)\mathbf{q}(j) \\ &-\begin{pmatrix} \phi(j)e_d(j)\boldsymbol{\gamma}_d \\ +\big(1-\phi(j)\big)e_p(j)\boldsymbol{\gamma}_p \end{pmatrix}\end{aligned} . \tag{27}$$

Finally, estimated data symbol of the desired user at j^{th} odd $(2j+1)$ and even $(2j)$ block sequences can be directly detected as

$$\begin{aligned}\hat{b}_{\mathrm{d}}(2j+1)&=\mathbf{f}^H(2j+1)\boldsymbol{\gamma}_d , \\ \hat{b}_{\mathrm{d}}(2j)&=\mathbf{f}^H(2j)\boldsymbol{\gamma}_d .\end{aligned} \tag{28}$$

The computational complexity of the SGD FD SF semiblind multiuser receiver with adaptive parameters is investigated in this subsection. The receiver involves three LMS algorithms in 1) for adapting the FD SF tap-weight coefficients vector, 2) adapting optimal mixing parameter, and 3) adapting optimal step-size. For updated odd and even tap-weight equalizers through (23)-(27), where each of these adaptive LMS algorithms have computational complexity in order of $O(N)$ [37-38]. Therefore, the proposed SGD FD SF semiblind multiuser receiver possesses computational complex is $O(N)$ whereas suboptimal FD receivers incur minimum computational complex are $O(N^2)$. Furthermore, the proposed SGD FD SF semiblind multiuser receiver with adaptive optimal mixing parameter has a less increasing rate of computational complexity than those of conventional FD SF AS-LMS training-based receives and FD SF AS-LMS semiblind multiuser with fixed mixing parameter receivers, whose computational complexities are $O(N)$.

4. System Parameters

The system parameters were derived according to an outdoor propagation scenario. We used a link level MIMO channel model which had been specifically developed within the Multi Element Transmit Receive Antennas (METRA) model for Mobile Broadband Wireless Access (MBWA) system MIMO channel project [39]. This channel model was based on 3GPP/3GPP2 proposal [17] for mobile broadband wireless MIMO channel exploiting multipath angular characteristics. It consists of elaborating a spatial model from the hybrid approach between a geometrical concept depending on cluster position and the tapped delay line model describing the average power delay profile with a fixed number of taps. The spatial parameters were defined at the BS and at MS. The angular distribution was modeled from parameters leading to an average of angle spread [40].

The Case B ITU Pedestrian A MIMO channel parameters with 0.5λ antenna spacing, uniform power azimuth spectrum (PAS) and angle of arrival (AOA) 22 degree was considered. The classical Rayleigh model was used to generate the uncorrelated fading signal. We used 3GPP2 MIMO channel power delay profile with a fixed number of taps [17] to model an outdoor environment which was characterized by a large delay spread, a higher mobility and a symmetrical antenna configuration.

We considered the system which was based on a sampling frequency 57.6 MHz with a carrier frequency of

5 GHz and the subcarriers equaled spreading code. The complex orthogonal FD spreading codes were employed as the user-specific code which had the length $N = 32$. The BS transmits QPSK symbol and all users had the same powers. The transmit power at antenna one and antenna two were normalized to one. The additive noise was an AWGN.

In simulation, MIMO radio channels were inserted between transmit and receive antennas of the SFBC downlink MIMO MC-CDMA system model. Besides, the correlation properties in the spatial domain of the broadband wireless MIMO channel were obtained from the Kronecker product of two independent correlation matrices which were defined by the correlation properties at the BS and MS and the associated Doppler spectrum of the channel part.

5. Simulation Results

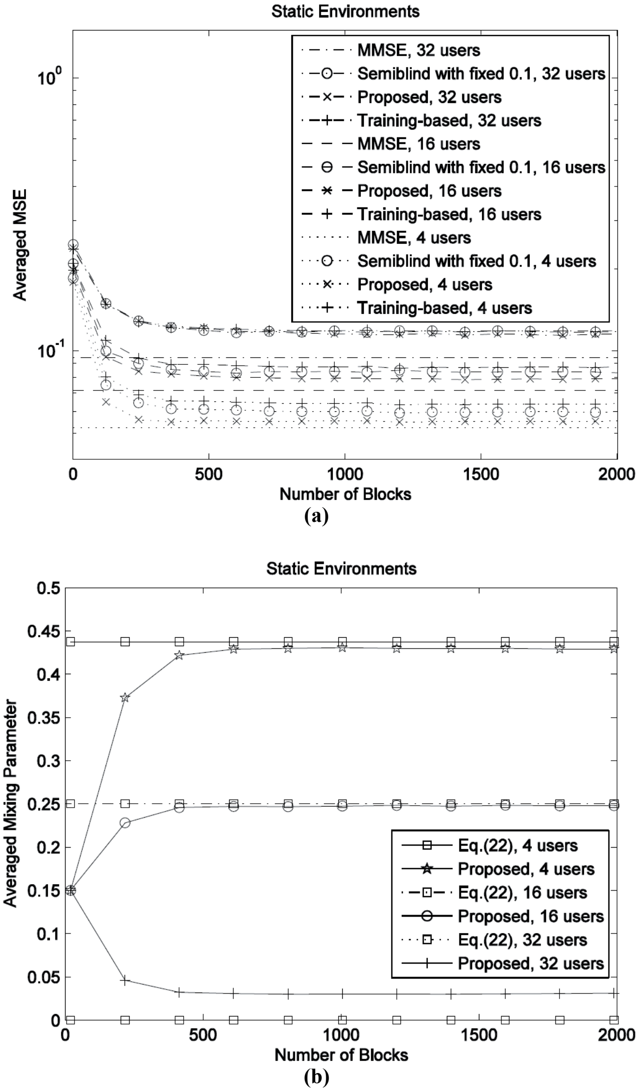
The performance of adaptive FD SF multiuser receivers were investigated, the proposed SGD semiblind multiuser receiver with adaptive optimal mixing parameter was compared with the conventional AS-LMS training-based, the AS-LMS semiblind with fixed mixing parameter $\phi_{\text{fixed}} = 0.1$, and the theoretical multiuser-trained MMSE receivers in SFBC downlink MIMO MC-CDMA with CPICH and without CP system under fast time varying multipath frequency-selective fading channels. The fixed mixing parameter $\phi_{\text{fixed}} = 0.1$ based on an optimal value which was proposed in [29]. The MIMO channel model was set based on the 3GPP2 modified Pedestrian A with a Doppler speed of 120 km/h.

The proposed semiblind and AS-LMS semiblind with fixed mixing parameter receivers assumed knowledge of the pilot and desired user code vectors. The AS-LMS training-based receiver assumed only knowledge of the pilot code vector. Theoretical multiuser-trained MMSE receiver assumed perfect knowledge of complex FD channel response, total received signal power and noise power, and updated using LS method with inverse matrix term.

We assumed throughout this section that the first user ($k = 1$) is the desired user. An initial step-size as μ_0 for the AS-LMS algorithms were chosen $\mu_0 = 1\times10^{-1}$. The upper and lower step-size limits μ^+ and μ^- were 0.5 and 0, respectively. Also, the adaptation factors α of 1×10^{-4} and β of 1×10^{-4} were selected. The initial mixing parameter ϕ_0 for the proposed algorithm was chosen as $\phi_0 = 0.15$ and the upper and lower mixing parameter limits ϕ^+ and ϕ^- were 1 and 0, respectively. All receivers used the same order of equalizer $L_f = 31$ and updated at block size. The static and dynamic environments were investigated in this section.

5.1 Static Environments

A system consisting of the pilot ($k = 0$), desired user ($k = 1$) and various amounts (2, 14 and 30) of equal power interfering users was considered. Fig. 2(a) illustrates an averaged MSE attaining from the proposed semiblind, AS-LMS semiblind with fixed mixing parameter, AS-LMS training-based and multiuser-trained MMSE algorithms at 4, 16 and 32 active loaded users existing in the system. The MSE value of the proposed semiblind algorithm at the steady state is lower than the AS-LMS semiblind with fixed mixing parameter and training-based algorithms in the case of 4 and 16 active loaded users existing in the system.



(a)

(b)

Fig. 2. **(a)** Averaged MSE's obtained from the proposed semiblind, theoretical multiuser-trained MMSE, AS-LMS semiblind with fixed mixing parameter and AS-LMS training-based algorithms, and **(b)** averaged mixing parameter trajectories obtained from the proposed semiblind and optimal mixing parameters predicted from (22) in the case of 4, 16 and 32 active loaded users existing in the system in modified Pedestrian A channel model with Doppler speed of 120 km/h.

Fig. 2(b) illustrates averaged mixing parameter trajectories from the proposed semiblind algorithm and the optimal mixing parameters ϕ_{opt} predicted from (22). At 4, 16 and 32 active loaded users existing in the system, the mixing parameter values from the proposed algorithm adapt closely to the optimal mixing parameter value.

Fig. 3 illustrates an averaged SER attaining from all algorithms where SNR = 10 dB was set. At SER = 1×10^{-4} in the case of half-loaded users ($K = 15$), the proposed semiblind algorithm achieves an improvement in reducing the transmit power approximately 1.1 dB and 2 dB over the AS-LMS semiblind with fixed mixing parameter and AS-LMS training-based algorithms, respectively. Moreover, we observe that the difference in the performance between the proposed semiblind, AS-LMS semiblind with fixed mixing parameter and AS-LMS training-based algorithms decreases where the number of active loaded users existing in the system increases. This consistency with the predicted optimal mixing parameter value (22) and simulation result is shown in Fig. 2. Thus, it can be explained that the semiblind algorithms depend on less information from the blind-based mode where the number of active loaded users existing in the system increases. Considering the case of full-loaded users ($K = 31$), the mixing parameter adapts towards zero (Fig. 2(b)) and the predicted optimal mixing parameter value equals zero ($\phi_{\text{opt}} = 0$). As a result, the semiblind algorithms converge to fully utilize information from training-based mode only. Clearly, the semiblind algorithms have the same performance as the training-based algorithm.

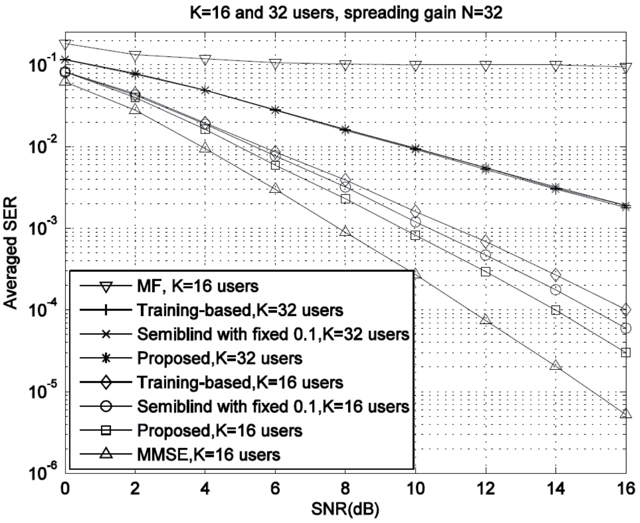


Fig. 3. Averaged SER's obtained from the proposed semiblind, matched filter (MF), AS-LMS training-based, AS-LMS semiblind with fixed mixing parameter and theoretical multiuser-trained MMSE receivers in the case of half-loaded users and full-loaded users in modified Pedestrian A channel models with Doppler speed of 120 km/h.

Fig. 4 illustrates an averaged SER versus the number of active loaded users existing in the system. In the case of weak-loaded and half-loaded users, the proposed semiblind algorithm outperforms the AS-LMS training-based, AS-LMS semiblind with fixed mixing parameter algorithms. However, the improvement declines where the number of active loaded users existing in the system increases.

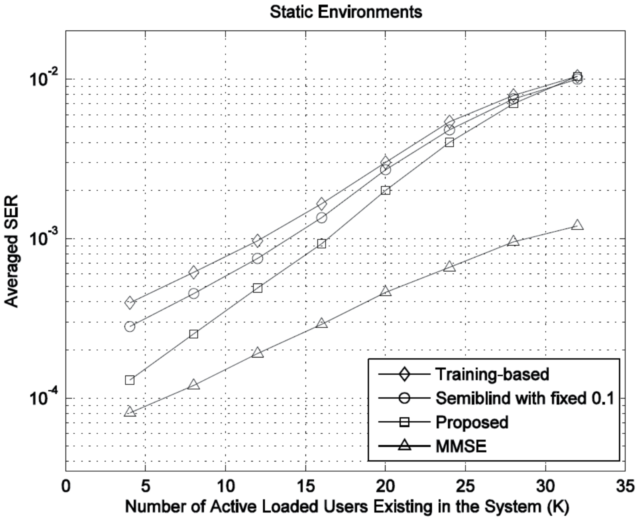


Fig. 4. Averaged SER's versus the number of active loaded users obtained from the proposed semiblind, AS-LMS training-based, AS-LMS semiblind with fixed mixing parameter and theoretical multiuser-trained MMSE receivers.

In this subsection, it is clear that the performance of semiblind algorithm has an improvement when the mixing ratio of information between blind-based mode and training-based mode is adapted to an optimal value.

5.2 Dynamic Environments

This simulation compares the tracking capability of each receiver in detection of the desired user in a dynamic environment where the number of active loaded users existing in the system changes abruptly. Simulation parameters were identical to the static environment case. At initial block time $j = 0$, pilot ($k = 0$), desired user ($k = 1$) and 14 interference users ($k = 2,\ldots,15$) were activated in the system. At $j = 600$, 12 interfering users ($k = 4,\ldots,15$) exited from the system. At $j = 1200$, 28 interfering users ($k = 4,\ldots,31$) entered the system. Fig. 5(a) illustrates the averaged SINR. The proposed semiblind algorithm responds to the abrupt change in the number of active loaded users. It offers SINR improvement of approximately 1 dB and 0.7 dB in the weak-loaded users, 0.5 dB and 0.3 dB in the half-loaded users, in detection of the desired user over AS-LMS training-based and AS-LMS semiblind with fixed mixing parameter algorithms, respectively. It is clear that the proposed semiblind multiuser with adaptive mixing parameter algorithm can suppress more interference users than existing algorithms. Fig. 5(b) shows the averaged step-size and the adaptive mixing parameter trajectories of the proposed semiblind algorithm. For a sudden change, the trajectories of the step-size and the mixing parameter adapt closely to the optimal values result of the receiver incorporating the adaptive mixing parameter and the AS-LMS. Furthermore, the semiblind algorithms mitigate the problem of SINR drop resulting from the use of a shared equalizer to detect the desired user as found in over existing conventional LMS training-based algorithm.

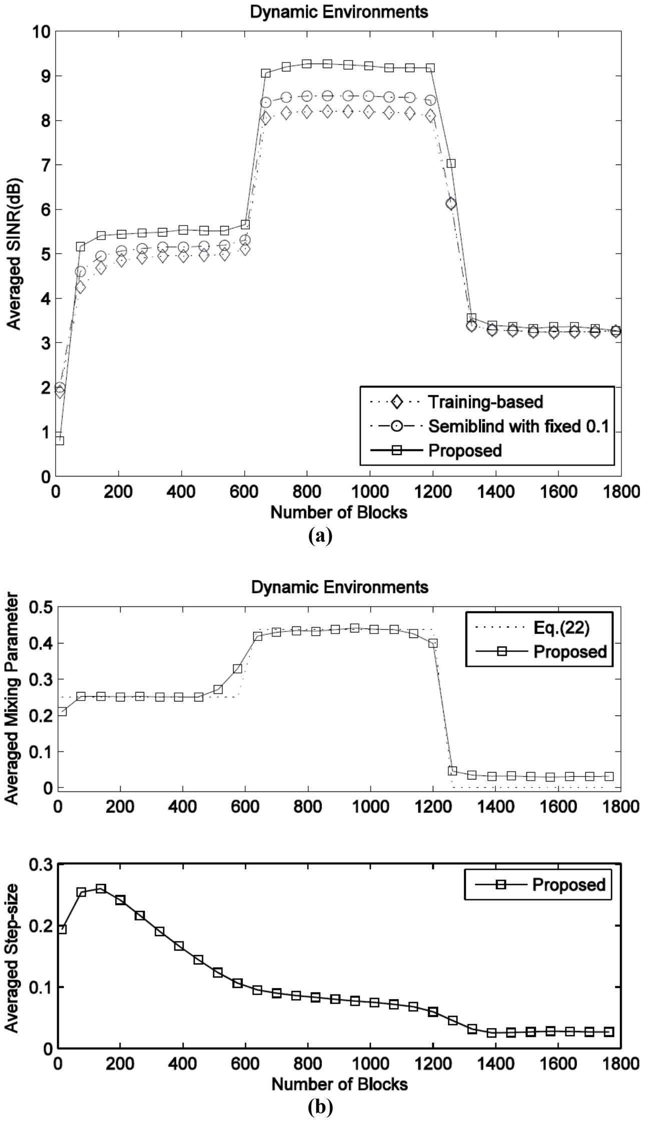


Fig. 5. **(a)** Averaged SINR's obtained from the proposed semiblind, AS-LMS training-based and AS-LMS semiblind with fixed mixing parameter receivers, and **(b)** averaged mixing parameter and averaged step-size trajectories obtained from the proposed semiblind receiver in sudden arrival of users and non-stationary multipath channel with Doppler speed of 120 km/h.

In summary, incorporating the adaptive optimal mixing parameter into a semiblind algorithm can improve performance of the semiblind with fixed mixing parameter receiver in both dynamic and static environments.

6. Conclusions

The analytical results in this paper show that the optimal mixing information ratio between blind-based mode and training-based mode of semiblind multiuser receivers relies on power and number of active loaded users existing in the systems. The SGD FD SF semiblind multiuser receiver with adaptive optimal mixing parameter has been proposed to improve performance of the semiblind multiuser receivers with fixed mixing parameter and to reduce computational complexity of the suboptimal semiblind multiuser receivers for SFBC downlink MIMO MC-CDMA with CPICH systems in multipath frequency-selective fading channel. The simulation results reveal that performance of the proposed receiver outperforms the existing FD SF semiblind with fixed mixing parameter and the conventional FD SF training-based multiuser receivers in MSE and SER. Moreover, the proposed receiver has an improvement in the SINR over existing FD SF multiuser receivers in a dynamic environment where the number of active loaded users existing in the system is changes abruptly.

Acknowledgements

This work was supported by the Thailand Research Fund (TRF) under Grant MRG5080027.

Appendix A:
Derivation of the FD SF Multiuser-trained MMSE Equalizer

Substituting (8) into optimal multiuser-trained MMSE cost function (14) and taking the expectation, we obtain

$$J(\mathbf{f}_{\mathrm{MMSE}}) = \mathrm{E}\left\{\left|\mathbf{f}_{\mathrm{MMSE}}^{H}(j)\mathbb{F}\left(\tilde{\mathbf{H}}\tilde{\mathbf{T}}(j)+\tilde{\mathbf{W}}(j)\right)-\mathbf{t}_{v}(j)\right|^{2}\right\},$$

$$=\left(\begin{array}{l}\mathbf{f}_{\mathrm{MMSE}}^{H}\mathbb{F}\left(\tilde{\mathbf{H}}\left(\underbrace{\mathrm{E}\left\{\tilde{\mathbf{T}}(j)\tilde{\mathbf{T}}^{H}(j)\right\}}_{\left(\sigma_t^2\right)\mathbf{I}}\right)\tilde{\mathbf{H}}^{H}+\underbrace{\mathrm{E}\left\{\tilde{\mathbf{W}}(j)\tilde{\mathbf{W}}^{H}(j)\right\}}_{\left(\sigma_w^2\right)\mathbf{I}}\right)\mathbf{f}_{\mathrm{MMSE}}\\ -\mathbf{f}_{\mathrm{MMSE}}^{H}\mathbb{F}\left(\tilde{\mathbf{H}}\right)\underbrace{\mathrm{E}\left\{\mathbb{F}\left(\tilde{\mathbf{T}}(j)\right)\mathbf{t}_{v}(j)\right\}}_{\left(\frac{\sigma_t^2}{N}\right)\mathbf{i}_{v}}+\underbrace{\mathrm{E}\left\{\mathbf{t}_{v}(j)\mathbf{t}_{v}(j)\right\}}_{\left(\frac{\sigma_t^2}{N}\right)}\end{array}\right). \tag{A.1}$$

Taking the gradient of (A.1) with respect to $\mathbf{f}_{\mathrm{MMSE}}$ and setting the result to zero gives us

$$\nabla_{\mathbf{f}}J_{\mathrm{MMSE}}=\left(\sigma_t^2\mathbf{H}\mathbf{H}^{H}+\sigma_w^2\mathbf{I}\right)\mathbf{f}_{\mathrm{MMSE}}-\frac{\sigma_t^2}{N}\mathbf{H}\mathbf{i}_{v}=0 \tag{A.2}$$

where $\mathbf{H}=\mathrm{F}\left(\tilde{\mathbf{H}}\right)$. Solving for $\mathbf{f}_{\mathrm{MMSE}}$, we obtain

$$\mathbf{f}_{\mathrm{MMSE}}=\frac{\sigma_t^2}{N}\left(\sigma_t^2\mathbf{H}\mathbf{H}^{H}+\sigma_w^2\mathbf{I}\right)^{\dagger}\mathbf{H}\mathbf{i}_{v}\,. \tag{A.3}$$

Appendix B:
Derivation of the FD SF Semiblind Multiuser Equalizer

Substituting (8) into suboptimal FD SF semiblind multiuser receiver with mixing parameter (17) and taking the expectation yields

$$\begin{aligned} J(\mathbf{f},\phi) &= \phi \mathrm{E}\left\{\left|\mathbf{f}^H \mathrm{F}\left(\mathbf{HT}(j)+\mathbf{W}(j)\right)\mathbf{c}_d^H - \hat{b}_d(j)\right|^2\right\} \\ &\quad + (1-\phi)\mathrm{E}\left\{\left|\mathbf{f}^H \mathrm{F}\left(\mathbf{HT}(j)+\mathbf{W}(j)\right)\mathbf{c}_p^H - b_p(j)\right|^2\right\}, \end{aligned}$$

$$\begin{aligned} &= \phi \left(\begin{array}{l} \mathbf{f}^H \mathbf{c}_d^H \mathbb{F}\left(\begin{array}{l}\tilde{\mathbf{H}}\left(\underbrace{\mathrm{E}\left\{\mathbf{T}(j)\mathbf{T}^H(j)\right\}}_{(\sigma_t^2)\mathbf{I}}\right)\tilde{\mathbf{H}}^H \\ +\underbrace{\mathrm{E}\left\{\tilde{\mathbf{W}}(j)\tilde{\mathbf{W}}^H(j)\right\}}_{(\sigma_w^2)\mathbf{I}}\end{array}\right)\mathbf{c}_d\mathbf{f} \\ +\mathbf{f}^H\mathbb{F}\left(\tilde{\mathbf{H}}\right)\underbrace{\mathrm{E}\left\{\mathbb{F}\left(\tilde{\mathbf{T}}(j)\right)\mathbf{c}_d^H\hat{b}_d(j)\right\}}_{A_d\mathbf{i}_v} + \underbrace{\mathrm{E}\left\{\hat{b}_d(j)\hat{b}_d(j)\right\}}_{A_d}\end{array}\right). \\ &+ (1-\phi) \left(\begin{array}{l} \mathbf{f}^H \mathbf{c}_p^H \mathbb{F}\left(\begin{array}{l}\tilde{\mathbf{H}}\left(\underbrace{\mathrm{E}\left\{\tilde{\mathbf{T}}(j)\tilde{\mathbf{T}}^H(j)\right\}}_{(\sigma_t^2)\mathbf{I}}\right)\tilde{\mathbf{H}}^H \\ +\underbrace{\mathrm{E}\left\{\tilde{\mathbf{W}}(j)\tilde{\mathbf{W}}^H(j)\right\}}_{(\sigma_w^2)\mathbf{I}}\end{array}\right)\mathbf{c}_p\mathbf{f} \\ -\mathbf{f}^H\mathbb{F}\left(\tilde{\mathbf{H}}\right)\underbrace{\mathrm{E}\left\{\mathbb{F}\left(\tilde{\mathbf{T}}(j)\right)\mathbf{c}_p^H b_p(j)\right\}}_{A_p\mathbf{i}_v} + \underbrace{\mathrm{E}\left\{b_p(j)b_p(j)\right\}}_{A_p}\end{array}\right) \end{aligned} \quad \text{(B.1)}$$

Taking the gradient of (B.1) with respect to **f** and setting to zero yields

$$\nabla_{\mathbf{f}} J = \left(\sigma_t^2\mathbf{H}\mathbf{H}^H + \sigma_w^2\mathbf{I}\right)\mathbf{f} - \left(A_p - \phi\left(A_p + A_d\right)\right)\mathbf{H}\mathbf{i}_v = 0 \,. \quad \text{(B.2)}$$

Hence, we obtain:

$$\mathbf{f} = \left(A_p - \phi\left(A_p + A_d\right)\right)\left(\sigma_t^2\mathbf{H}\mathbf{H}^H + \sigma_w^2\mathbf{I}\right)^{\dagger}\mathbf{H}\mathbf{i}_v \,. \quad \text{(B.3)}$$

References

[1] OJANPERA, T., PRASAD, R. An overview of air interface multiple access for IMT-2000/UMTS. *IEEE Communications Magazine*, 1998, vol. 36, no. 9, p. 82-86, 91-95.

[2] ADACHI, F., SAWAHASHI, M., SUDA, H. Wideband DS-CDMA for next-generation mobile communication systems. *IEEE Communication Magazine*, 1998, vol. 36, p. 56-69.

[3] YEE, N., LINNARTZ, J.-P., FETTWEIS, G. Multicarrier CDMA in indoor wireless radio network. In *Proceedings of the Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC 1993*. Yokohama (Japan), 1993, p. 109-113.

[4] PLASS, S., KAISER, S. MC-CMDA versus OFDMA in cellular environments. In *Proceeding European Signal Processing Conference (EUSIPCO'2005)*. Antalya (Turkey), 2005, p. 1-4.

[5] CHOULY, A., BRAJAL, A., JOURDAN, S. Orthogonal multicarrier techniques applied to direct sequence spread spectrum CDMA systems. In *Proceedings of IEEE GLOBECOM*. 1993, vol. 3, p. 1723-1728.

[6] YANG-SEOK CHOI, VOLTZ, P. J., CASSARA, F. A. On channel estimation and detection for multicarrier signals in fast and selective Rayleigh fading channels. *IEEE Transaction on Signal Communication*, 2001, vol. 49, p. 1375-1387.

[7] XIAODONG CAI, GIANNKIS, G. B. Low complexity ICI suppression for OFDM over time and frequency-selective Rayleigh fading channels. In *Proceeding of Asilomar Conference on Signals, Systems and Computers*. 2002, p. 1822-1826.

[8] ALAMOUTI, S. M. A simple transmit diversity technique for wireless communications mobile system. *Journal on Selected Areas in Communication*, 1998, vol. 16, no. 8, p. 1451-1458.

[9] ZEXIAN LI, LATVA-AHO, M. Performance of space-time block coded MC-CDMA in Nakagami fading channel. *Electronic Letters*, 2003, vol. 39, p. 222-224.

[10] XIAOYU HU, YONG-HUAT CHEW On the performance and capacity of an asynchronous space-time block-code MC-CDMA system in the present of carrier frequency offset. *IEEE Transactions on Vehicular Technology*, 2004, vol. 53, no. 5, p. 1327-1340.

[11] KAFLE, P. L., SESAY, A. B. Iterative semiblind multiuser receivers for space-time block-coded MC-CDMA uplink system. *IEEE Transactions on Vehicular Technology*, 2004, vol. 53, no. 5, p. 601-610.

[12] LINDSKOG, E., PAULRAJ, A. A transmit diversity scheme for channels with intersymbol interference. In *Proceeding of the International Conference on Communication ICC 2000.* New Orleans (USA), June 2000, vol. 1, p. 307-311.

[13] DEHGHANI, M. J., ARAVIND, R., JAM, S., PRABHU, K. M. Space-frequency block coding in OFDM systems. In *Proceeding IEEE TENCON*. 2004, vol. 1, p. 543-546.

[14] XIAOJUN WU, QINYE YIN, HANGUO ZHANG, KE DENG Time-domain multiuser detection for MC-CDMA systems without cyclic prefix. In *Proceedings of IEEE International Conference on Communication ICC 2002*. New York (USA), 2002, p. 921-925.

[15] WEISS, A. J., FRIEDLANDER, B. Channel estimation for DS-CDMA downlink with aperiodic spreading codes. *IEEE Transactions on Communication*, 1999, vol. 47, no. 10, p. 1561-1569.

[16] PUNNOOSE, S., ZHU XU, NANDI, A. K. Blind channel estimation for MIMO uplink single carrier CDMA block transmission systems. In *Proceedings of the 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC'2007*. Athens (Greece), 2007, p. 1-5.

[17] *3GPP/3GPP2 25.996 v6.1.0 (2003-09).* Spatial channel model for multiple input multiple output (MIMO) simulations (Release6). Available at: http://www.quintillion.co.jp/3GPP/Specs; in 3Gpp, Spatial Channel.

[18] ZHIGUO DING, WARD, D. B. Semi-blind equalization for space time block codes and its ambiguity analysis. In *Proceeding of IEEE International Conference on Communication ICC 2004*. Paris (France), 2004, p. 2357-2361.

[19] AKTAS, E., MITRA, U. Semiblind channel estimation for CDMA systems with parallel data and pilot signals. *IEEE Transaction on Communication*, 2004, vol. 52, no. 7, p. 1102-1112.

[20] ZHIGUO DING, WARD, D. B. Direct semi-blind MMSE equalization for STBC. *IEEE Signal Processing Letters*, 2005, vol. 12, no. 5, p. 380-383.

[21] MOON, T. K. The expectation-maximization algorithm. *IEEE Signal Processing Magazine*, 1996, vol. 13, p. 46-60.

[22] ZEXIAN LI, LATVA-AHO, M. Nonblind and semiblind space-frequency multiuser detection for multirate MC-CDMA systems. *IEEE Transactions on Signal Processing*, 2006, vol. 54, no. 11, p. 4393-4404.

[23] MURTHY, CH. R., JAGANNATHAM, A. K., RAO, B. D. Training-base and semiblind channel estimation for MIMO systems with maximum ratio transmission. *IEEE Transactions on Signal Processing*, 2006, vol. 54, no. 7, p. 2546-2558.

[24] SHYNK, J. J. Frequency-domain and multirate adaptive filtering. *IEEE Signal Processing Magazine*, 1992, vol. 9, no. 1, p. 14-37.

[25] ZHENG, Y. R.., CHENGSHAN XIAO Channel estimation for frequency-domain equalization of single-carrier broadband wireless communications. *IEEE Transactions on Vehicular Technology*, 2009, vol. 58, no. 5, p. 815-823.

[26] LAI-U CHOI, MURCH, R. D. A transmit MIMO scheme with frequency domain pre-equalization for wireless frequency selective channels. *IEEE Transactions on Wireless Communication*, 2004, vol. 3, no. 3, p. 929-938.

[27] COON, J., ARMOUR, S., BEACH, M., MCGEEHAN, J. Adaptive frequency-domain equalization for single-carrier multiple-input multiple-output wireless transmissions. *IEEE Transactions on Signal Processing*, 2005, vol. 53, no. 8, p. 3247-3256.

[28] QING ZHAO, ZHONGPEI ZHANG, ZHIPING SHI Research and link simulation of key technologies for LTE. In *Proceeding of the 6th International Conference on Wireless Communications, Networking, and Mobile Computing WiCOM'2010*. Chengdu (China), 2010, p. 1-4.

[29] PETRÉ, F., LEUS, G., DENEIRE, L., ENGELS, M., MOONEN, M., DE MAN, H. Space-time block coding for single-carrier block transmission DS-CDMA downlink. *IEEE Journal on Selected Areas in Communication*, 2003, vol. 21, no. 3, p. 350-361.

[30] HUI LU, QIXING WANG, YONGYU CHANG, DACHENG YANG SVD-based frequency domain equalizer for MIMO-CDMA systems using virtual antenna. In *Proceeding of the 67th Vehicular Technology Conference IEEE-VTC'2008*. Singapore, 2008, p. 1-5.

[31] YANG HU, ASTELY, D., BALDEMAIR, R., FALAHATI, S. Semi-blind multiuser detection for LTE PUCCH. In *Proceeding of the IEEE Wireless Communication and Networking Conference WCNC 2009*. Budapest (Hungary), 2009, p. 1-5.

[32] BANGWON SEO, WOO-GEUN AHN, CHEOL JEONG, HYUNG-MYUNG KIM Fast convergent LMS adaptive receiver for MC-CDMA systems with space-time block coding. *IEEE Communications Letters*, 2010, vol. 14, no. 8, p. 737-739.

[33] LIJUN SUN, XIANGLI WANG, SHOUYONG ZHANG. A novel frequency domain equalization algorithm for SC-FDE system. In *Proceeding of Pacific-Asia Conference on Knowledge Engineering and Software Engineering KESE'09*. Shenzhen (China), 2009, p. 132-135.

[34] MASUD RANA, MD., KIM, J., CHO, W. K. LMS based adaptive channel estimation for LTE uplink. *Radioengineering*, 2010, vol. 19, no. 4, p. 678-688.

[35] VAN ACKER, K., LEUS, G., MOONEN, M., VAN DE WIEL, O., POLLET, T. Per tone equalizer for DMT-based systems. *IEEE Transactions on Communications*, 2001, vol. 49, no. 1, p. 109 to 119.

[36] YUVAPOOSITANON, P., PHROMPICHAI, S., CHAMBER, J. A. An adaptive step-size LMS chip equalizer for long-code downlink CDMA. In *Proceeding ECTI' 2003*, 2003, p. 210-213.

[37] KRISHNAMURTHY, V., YIN, G., SINGH, S. Adaptive step-size algorithms for blind interference suppression in DS/CDMA systems. *IEEE Transactions on Signal Processing*, 2001, vol. 49, no. 1, p. 190-201.

[38] KNUTH, D. E. *The Art of Computer Programming*. 2nd ed. Addison-Wesley Publish Company, 1981.

[39] IEEE802.20 working group on mobile broadband wireless access channel models for IEEE 802.20 MBWA systems. Available at: http://www.ieee802.org/20/Contribs/C802.20-03-70.pdf.

[40] KERMOAL, J. P., K., SCHUMACHER, L., PEDERSEN, K. I., MOGENSEN, P. E., FREDERIKSEN, F. A stochastic MIMO radio channel model with experimental validation. *IEEE Journal on Selected Areas in Communications*, 2002, vol. 20, no. 6, p. 1211-1226.

About Authors

Samphan PHROMPICHAI was born in Thailand. He received the Ph.D. degree in Electrical Engineering from Mahanakorn University of Technology, Thailand in 2005. He is an assistance professor at the department of electronic engineering, Mahanakorn University of Technology. His general research interests include digital signal processing and wireless communication.