

Successful interference cancellation with Blind Equalization method for MC-CDMA wireless communication system

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Abstract— The increasing demand for wireless services has created the need for cost effective transmission techniques that can exploit scarce spectral resources efficiently. In order to achieve the high data rates needed to meet the quality of service requirements of future multimedia applications, MC-CDMA has been considered as good air-interface candidate, especially for the downlink. However, the user capacity of MC-CDMA system is essentially limited by interference. This interference can be mitigated by employing precoding techniques, IB-DFE based receivers and other efficient interference suppression techniques. In the proposed system, combined Iterative IA precoding at the transmitter with IB-DFE based processing at the receiver is suggested for MC-CDMA systems. The matrices for this nonlinear space-frequency equalizer are obtained by minimizing the overall MSE of all data streams at each subcarrier.

Index Terms—BER, IA Precode, IB DFE, IL, MC-CDMA, MIMO, MSE, SNR.

1 INTRODUCTION

Multiple access techniques are to allow large number of mobile users to share the allocated spectrum in the most efficient manner. As the spectrum is limited, the sharing is required to increase the capacity of a cell or over a geographical area by allowing the available bandwidth to be used at the same time by different users and this must be done in such a way that the quality of service doesn't degrade within the existing users. Spread Spectrum Multiple Access (SSMA) uses signals which have transmission bandwidth whose magnitude is greater than the minimum required bandwidth. A Pseudo Noise (PN) sequence converts a narrow band signal to a wide band noise like signal before transmission [10]. There are two main types of spread spectrum multiple access techniques:

1. Frequency hopped Spread Spectrum (FHSS).
2. Direct sequence Spread Spectrum (DSSS).

Code division multiple access (CDMA) is a channel access method used by various radio communication technologies [12]. CDMA is a multiple access scheme, where several transmitters can send information simultaneously over a single communication channel. This allows several users to share a band of frequencies. For avoiding undue interference between the users, CDMA employs spread-spectrum technology and a special coding scheme where each transmitter is assigned a code. In this standard, the frequency range is: 869-894 MHz (for Receiver) and 824-849 MHz (for Transmitter). In such a system, there are a total of 20 channels and 798 users per channel. For each channel, the bit rate is 1.2288 Mbps. For the orthogonality, it usually combines 64 Walsh-Hadamard codes and m-sequence. In DS-SS, the message signal is multiplied by a Pseudo Random Noise Code. Each user is given his own codeword which is orthogonal to the codes of other users and in order to detect the user, the receiver must know the codeword used by the transmitter. There are, however, two problems in such systems which are discussed in the sequence.

In CDMA, self-interference arises from the presence of delayed replicas of signal due to multipath. The delays cause the spreading sequences of the different users to

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lose the orthogonality, as by design they are orthogonal only at zero phase offset. Hence in dispreading a given user's waveform, nonzero contributions to that user's signal arise from the transmissions of the other users in the network. This is distinct from both TDMA and FDMA, wherein for reasonable time or frequency guardbands, respectively, the orthogonality of the received signals can be preserved. The near-far problem is a serious one in CDMA [13]. This problem arises from the fact that signals closer to the receiver of interest are received with smaller attenuation than are signals located further away. Therefore the strong signal from the nearby transmitter will mask the weak signal from the remote transmitter. In TDMA and FDMA, this is not a problem since mutual interference can be filtered. In CDMA, however, the near-far effect combined with imperfect orthogonality between codes (e.g. due to different time shifts), leads to substantial interference.

Frequency Hopped Spread Spectrum (FHSS) is a digital multiple access system in which the carrier frequencies of the individual users are varied in a pseudo random fashion within a wideband channel [11]. The digital data are broken into uniform sized bursts which are then transmitted on different carrier frequencies. A direct sequence modulated signal whose center frequency is made to hop periodically in a pseudo random fashion is used in this technique. One of the advantages using this technique is they avoid near-far effect. However, frequency hopped CDMA systems are not adaptable to the soft handoff process since it is difficult to synchronize the frequency hopped base station receiver to the multiple hopped signals.

In OFDM a large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels [11]. Each sub-carrier is modulated with a conventional modulation scheme such as Quadrature Amplitude Modulation (QAM) or Phase-Shift Keying (PSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [10]. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrow band signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate Inter Symbol Interference (ISI) and utilize echoes and time-spreading to achieve a diversity

gain, i.e. a signal-to-noise ratio improvement [11]. This mechanism also facilitates the design of Single Frequency Networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

2 EXISTING SYSTEM

The increasing demand for wireless services has created the need for cost effective transmission techniques that can exploit scarce spectral resources efficiently. In order to achieve the high bit rates needed to meet the quality of service requirements of future multimedia applications, Multi-Carrier Code Division Multiple Access (MC-CDMA) has been considered as good air-interface candidate, especially for the downlink. This scheme combines efficiently OFDM and CDMA [12]. Therefore, MC-CDMA benefits from OFDM characteristics such as high spectral efficiency and robustness against multipath propagation, while CDMA allows a flexible multiple access with good interference properties [4]. However, the user capacity of the MC-CDMA system is essentially limited by interference. This interference can be mitigated by employing precoding techniques, iterative block decision feedback equalization (IB-DFE) based receivers and other efficient interference suppression techniques, proposed for different scenarios [1]. Multi-Carrier Code Division Multiple Access (MC-CDMA) is a multiple access scheme used in OFDM-based telecommunication systems, allowing the system to support multiple users at the same time.

MC-CDMA spreads each user symbol in the frequency domain. Each user symbol is carried over multiple parallel subcarriers, and it is phase shifted according to a code value. The code values differ per subcarrier and per user. The receiver combines all subcarrier signals, by weighing these to compensate varying signal strengths and undo the code shift. The receiver can separate signals of different users, because these have different code values. In the downlink, that is one base station transmitting to one or more terminals, the MC-CDMA typically reduces to Multi-Carrier Code Division Multiplexing [10]. All user signals can easily be synchronized, and all signals on one subcarrier experience the same radio channel properties. In such case a preferred system implementation is to take N user bits possibly but not necessarily for different destinations, to transform these using a Walsh

Hadamard Transform, followed by an Inverse Fast Fourier Transform (IFFT).

3 PROPOSED SYSTEM

MIMO MC-CDMA systems with iterative IA precoding at transmitter and iterative frequency domain receivers based on the IB-DFE concept is considered. IA based techniques achieve the maximum DoF in MIMO interference channels. However, they cannot efficiently exploit the space-frequency diversity. On the other hand, IB-DFE based receivers are well known to be one of the most efficient techniques to exploit this space-frequency diversity [6]. Therefore, this combination allows us to design a system that is able to achieve maximum DoF and exploit the high diversity order inherent to these systems [1]. Conventional Frequency Domain Equalization (FDE) schemes employ a linear FDE optimized under the minimum mean square error (MMSE) criterion [12]. However, the residual interference levels might still be too high, leading to performance that is still several dB from the Matched Filter Bound (MFB). Nonlinear time-domain equalizers are known to outperform linear equalizers and conventional, time-domain DFEs are known to have good performance complexity tradeoffs. For this reason, there has been significant interest in the design of nonlinear FDEs in general and frequency-domain FDEs in particular, with the IB-DFE being the most promising nonlinear FDE. IB-DFE was used for a wide range of scenarios in the last 10 years, ranging from diversity scenarios, the MIMO systems and the MC-CDMA systems, among many others.

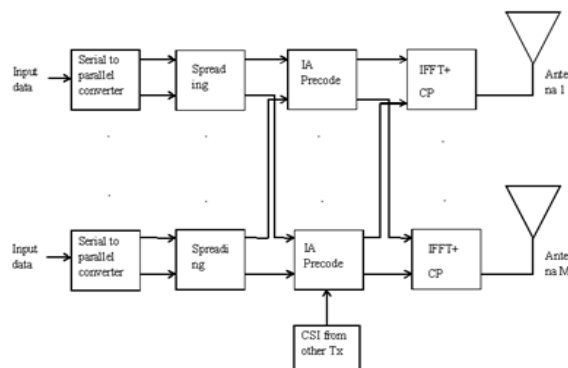


Fig. 1. Block Diagram of Proposed IA precoded MC-CDMA transmitter.

In the proposed scheme the chips are IA-precoded instead of the data symbols as in narrowband or OFDM based systems. The proposed receiver structure is designed in two steps: first a linear filter is used to mitigate the inter-user aligned interference, and then an IB-DFE based equalizer is employed to

efficiently separate the spatial streams. The receiver structure is sited in fig (3.2). The matrices for these non-linear space-frequency equalizers are obtained by minimizing the overall Mean Square Error (MSE) of all data streams at each subcarrier. In the design of the equalizer, explicitly take into account the residual inter-user interference, allowing not only an efficient separation of the spatial streams but also a reduction the number of iterations in the IA procedure, and thus also reducing the information needed to be exchanged between the different transmitter-receiver pairs. Furthermore, a simple, yet accurate analytical approach is used for obtaining the performance of the proposed receiver structure.

The incoming data streams are converted from serial to parallel and spread using spreading codes. After spreading Interference Alignment (IA) precoding done to avoid overall interference and to provide minimum DoF. After that IFFT performed and cyclic prefix inserted and transmitted. The proposed transmitter is shown in the above figure.

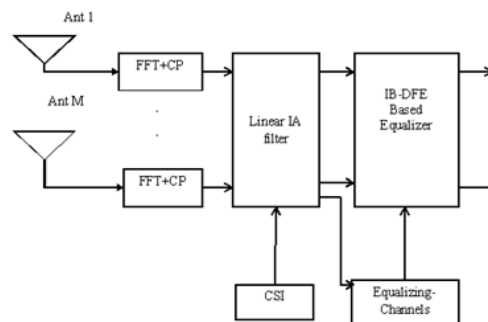


Fig. 2. Block Diagram of Proposed MC-CDMA receiver.

IB-DFE can be regarded as a low complexity turbo equalizer implemented in the frequency-domain that does not require the channel decoder output in the feedback loop, although true turbo equalizers based on the IB-DFE concept can also be designed [1]. An IB-DFE-based scheme specially designed for offset constellations such as OQPSK, and OQAM. In the context of cooperative systems, an IB-DFE approach was derived to separate the quantized received signals from the different base stations. IB-DFE based receivers are well known to be one of the most efficient techniques to exploit this space-frequency diversity.

3.1 System Model

A K-user MIMO interference channel with constant coefficients on a per-subcarrier basis is considered. It comprises K transmitter-receiver pairs sharing the same

physical channel, where a given transmitter only intends to have its P_k spatial data symbols on each subcarrier decoded by a single receiver. Without loss of generality, consider a symmetric case where all transmitters and receivers have M antennas, and $P_k = P \forall k$, which is denoted by an (M, M, K) interference channel with P data symbols per subcarrier. It has been shown that for $K \leq 3$, the number of spatial DoF achievable in an (M, M, K) interference channel is $KM/2$ while for $K > 3$ the overall spatial DoF achievable is only $P_t = \sum_{k=1}^K P_k > 2M - 1$. Therefore, this system achieves $KM/2$ and P_t spatial DoF per-subcarrier for $K \leq 3$ and $K > 3$ respectively. As can be seen, each one of the P L -length data symbols blocks, $\{d_{k,p,l}; k = 1, \dots, K, p = 1, \dots, P, l = 0, \dots, L - 1\}$ where the constellation symbol $d_{k,p,l}$ is selected from the data according to given mapping rule, is spread into L chips using orthogonal Walsh-Hadamard codes, leading to the block $\{s_{k,p,l}; p = 1, \dots, P, l = 0, \dots, L - 1\}$. Then, a set of P chips (one of each block) is weighted by an IA-precoding matrix. Note that here the IA-precoding is applied on a chip level instead of data level as in the conventional IA systems. The signal after the IA precoding at the k th transmitter subcarrier l can be written as

$$X_{k,l} = W_{k,l} s_{k,l} \quad (1)$$

Where $W_{k,l} \in C^{M \times P}$ is the linear precoding matrix computed at the k th transmitter on subcarrier l , constrained to $\|W_{k,l}\|_F^2 \leq T_p$ and T_p is the transmit power at the transmitters with $s_{k,l} = [s_{k,1,l}, \dots, s_{k,P,l}]^T$. The received frequency-domain signal (i.e., after cyclic prefix removal and FFT operation) for the k th receiver and the l th subcarrier is given by,

$$y_{k,l} = H_{k,k,l} W_{k,l} s_{k,l} + \sum_{j=1, j \neq k}^K H_{k,j,l} W_{j,l} s_{j,l} + n_{k,l} \quad (2)$$

The size $M \times M$ matrix

$$H_{k,j,l} = \sqrt{\alpha_{k,j}} H_{k,j,l}^{(iid)} \quad (3)$$

denotes the overall channel between the transmitter j and receiver k on subcarrier l , where $H_{k,j,l}^{(iid)}$ contains the fast fading coefficients which is assumed to have i.i.d $CN(0, 1)$ entries independent, identically distributed complex normal random variables) and $\alpha_{k,j}$ represents the long term channel power on the same link. $n_{k,l}$ is the additive white Gaussian noise (AWGN) vector at receiver k on subcarrier l , i.e., $n_{k,l} \sim CN(0, \sigma_n^2 I_M)$. The detection procedure is done in two steps: first a linear filter is used to mitigate the aligned user's interference. Thus, the signal after the filtering process is given by,

$$\hat{y}_{k,l} = \Phi_{k,l}^H H_{k,k,l} W_{k,l} s_{k,l} + \Phi_{k,l}^H \sum_{j=1, j \neq k}^K H_{k,j,l} W_{j,l} s_{j,l} + \Phi_{k,l} n_{k,l} \quad (4)$$

Where $\Phi_{k,l} \in C^{M \times P}$ denotes the linear receiving filter. Second a non-linear equalizer based on IB-DFE principle is designed to efficiently separate the spatial P L -length data block, considering the equivalent channels provided by the first block.

3.2 IA Precoding

The functioning is based on Iterative Minimum Interference Leakage (IL) IA precoding algorithm [1]. The subspace, with orthonormal basis $\Phi_{k,l}$ and precoders are jointly designed to optimize an appropriate cost function. The global function to optimize is

$$S_{IL} = \sum_{k=1}^K \sum_{j=1, j \neq k}^K \|\Phi_{k,l}^H H_{k,j,l} W_{k,j,l}\|_F^2 \quad (5)$$

This is usually denoted by IL.

A simple approach to solve this problem is to use an alternating minimization procedure. This algorithm takes the following iterative form:

1) Define an arbitrary orthogonal basis $\Phi_{k,l}$ or each receiver subspace on each subcarrier.

2) Find the precoder matrix $W_{j,l}$ such that each node has maximum squared Euclidean distance between it and the subspace spanned by the columns of each $\Phi_{k,l}$ by using

$$W_{j,l} = \mathcal{V}_{min}^P \left(\sum_{\substack{k=1 \\ k \neq j}}^K H_{k,j,l}^H \Phi_{k,l} \Phi_{k,l}^H H_{k,j,l} \right) \quad (6)$$

3) Update the receiver orthonormal subspaces according to

$$\Phi_{k,l} = \mathcal{V}_{min}^P \left(\sum_{\substack{j=1 \\ j \neq k}}^K H_{k,j,l} \Phi_{j,l} W_{j,l}^H H_{k,j,l}^H \right) \quad (7)$$

4) Repeat steps 2 and 3 until convergence. This can be carried out until $\mathfrak{I}_{IL}(t) < \varepsilon$ if feasibility conditions are met, or $\mathfrak{I}_{IL}(t-1) - \mathfrak{I}_{IL}(t) < \varepsilon$. Otherwise, for an arbitrary threshold ε . The index t refers to the iteration number and it was dropped in the above equations for simplicity.

4 RESULTS AND DISCUSSION

Performance results are analyzed for the proposed receiver structure that is for IA precoding with IB-DFE based equalizer.

Input data were generated for user 1 and user 2. The number of bits for user 1 is $N=100$, the number of bits

considered for user 2 is $M=100$. The input data generated are shown in figure 3 and figure 4. Spreading is done for the generated data.

Here spreading is done in the frequency domain. For the purpose of spreading Walsh Hadamard codes are used. The spread data for user 1 and user 2 are shown in figure 5 and figure 6. For converting spread data into OFDM signals, Inverse Fourier Transform (IFFT) need to be performed. Signals generated by IFFT for user 1 and user 2 are shown in figure 7 and figure 8.

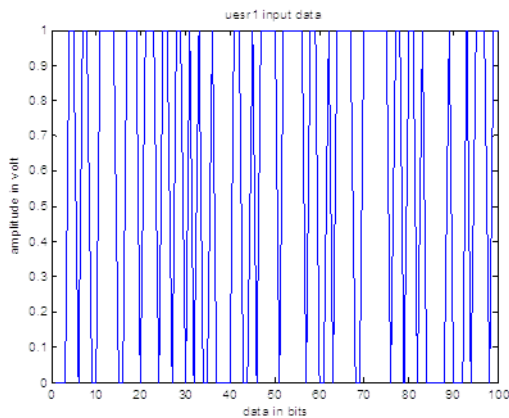


Fig. 3. Input data for user 1.

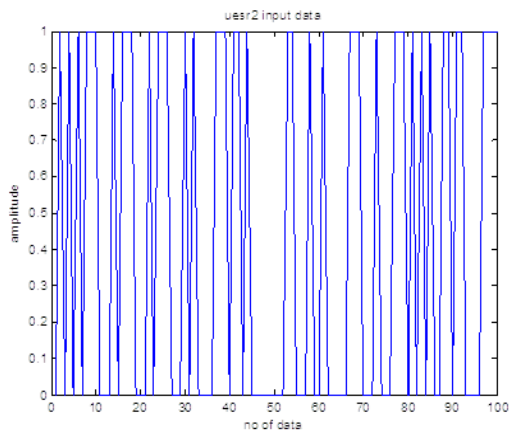


Fig. 4. Input data for user 2.

The generated signals are combined and transmitted through the Additive White Gaussian Noise (AWGN) channel. The data transmission is shown in figure 9.

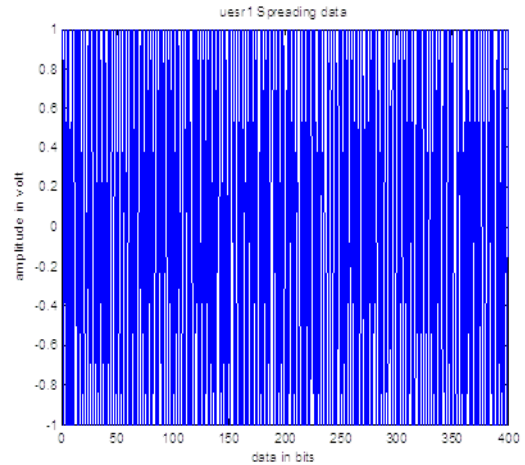


Fig. 5. Spread Data for user 1.

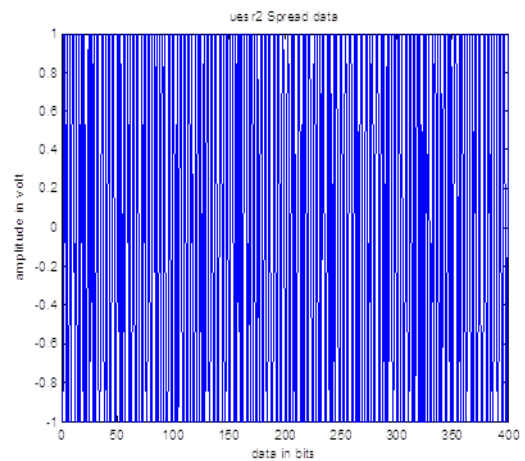


Fig. 6. Spread data for user 2.

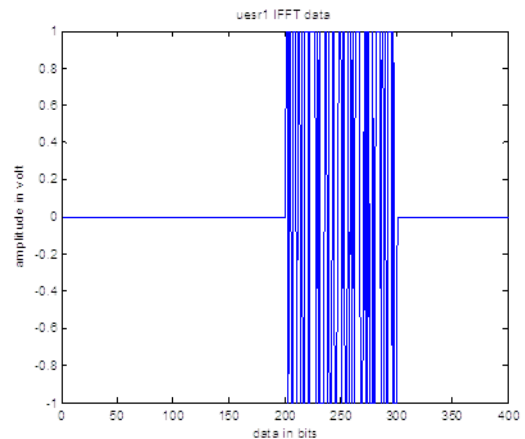


Fig. 7. IFFT on user 1.

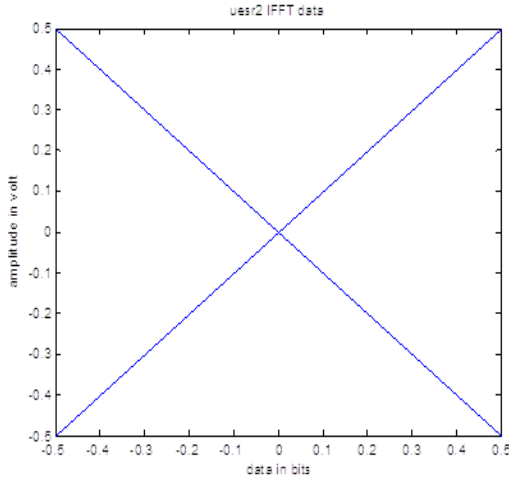


Fig. 8.IFFT on user 2.

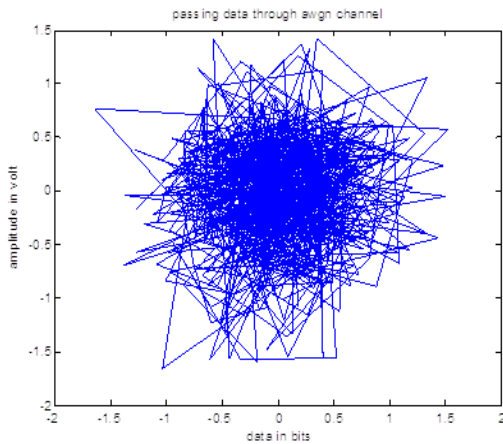


Fig. 9.Data transmission over AWGN.

4.1 Performance Results for IA precoded MC-CDMA

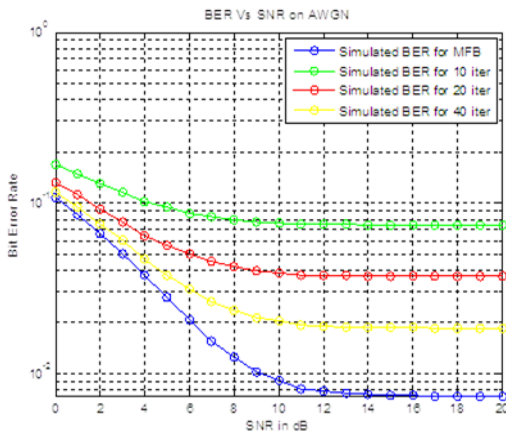


Fig. 10.BER versus SNR.

The performance results are presented in terms of the average bit error rate (BER) as a function of E_b/N_0 with

E_b denoting the average bit energy and N_0 denoting the one-sided noise power spectral density.

From figure 10 it is observed that the BER performance approaches the MFB after a few iterations (typically 10, 20 or 40 iterations). In this scenario the IB-DFE based equalizer must deal with inter block interference, since 1000-length blocks are transmitted simultaneously by each transmitter. Therefore, the proposed scheme is quite efficient to separate the spatial streams and achieve the high diversity order inherent to this scenario, with only a few iterations.

5 CONCLUSION

In the proposed system IA precoding is considered on a per subcarrier basis, at the transmitter with IB-DFE based processing at the receiver for MIMO MC-CDMA systems. The proposed receiver structure was considered to mitigate the inter-user aligned interference, and then an iterative frequency-domain equalizer was designed to efficiently separate the spatial streams.

The performance analysis in terms of BER and SNR was obtained and was concluded that performance could be much enhanced by increasing the number of iterations. The work was a complicated one as this has to include both IA precoding and IB-DFE concept. The system suffers from the drawback of reduced data rate and reduced quality. However could be overwhelmed by the combined advantages of both IA precoding and IB-DFE equalization.

6 FUTURE ENHANCEMENT

Conventional equalizations minimizing mean-square error generally require a training sequence accompanying the data sequence. So, in the future work Blind Equalization based on Modified Constant Modulus Algorithm could be introduced which improves the data rate and quality. The commonly used adaptive algorithm for blind channel equalization is the Constant Modulus Algorithm (CMA), which uses the constant modularity of the signal as the desired property. The algorithm exhibits slow convergence rate and large steady state mean square error and the phase-blind nature in comparison with the algorithms used in conventional data-aided equalization schemes.

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