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Channel Estimation and Beamforming Techniques in Multiuser MIMO-OFDM Systems

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Abstract: Multiple antenna communication has become one of the major focuses in wireless communication research. Transmit beamforming with receive combining is a simple method for exploiting the significant diversity provided by multiple-input-multiple-output (MIMO) systems and the use of orthogonal frequency division multiplexing (OFDM) enables low complexity implementation of this scheme over frequency selective MIMO channels. A major challenge to MIMO-OFDM systems is how to obtain the channel state information accurately and promptly for coherent detection of information symbols and channel synchronization. This paper describes three beamforming techniques to MIMO-OFDM system and LSE channel estimation to improve the BER performance of the system.

Keywords: Channel Estimation, MIMO-OFDM, Beamforming.

I. INTRODUCTION

Beamforming is a signal processing technology that is used to direct the reception or transmission (the signal energy) of an array in a chosen angular direction. Classically, beamforming works by setting the antenna element weights so that the beam is concentrated on a signal coming from one particular direction while striving to ignore interference from other directions. In multipath, where the same signal is incident from several different directions, the number of directions normally exceeds the degrees of freedom 1 available from the array. But as long as the degrees of freedom exceed the number of different signals, then beamforming is still possible, although, in this case, the directional beams themselves are hard to interpret. Clearly, beamforming is only possible when there are multiple antennas, and these can be at either the transmitter or the receiver, or both. This paper presents three beamfoming design methods, derived from the convergence criteria for multi-objective optimization. Beamforming is proven to be possible for any combination of communications objective functions such as mean square error, signal-to-interference plus noise ratio, and leakage interference. This paper presents three beamforming designs for multiuser MIMO-OFDM, where the transmit and receive beamformers are obtained iteratively with closed-form steps. In the first case, the transmit (Tx) beamformers are set and the receive (Rx) beamformers are calculated. It works by projecting the Tx beamformers into a null space of appropriate channels. This eliminates one interference term for each user. Then the Rx beamformer for each user maximizes its instantaneous signal-to-noise ratio (SNR) while satisfying an orthogonality condition to eliminate the remaining interferences. The second case is jointly optimizing the Tx and Rx beamformers from constrained SNR maximization. It uses the results from the first case. The third case is also for joint optimization of Tx-Rx beamformers but combines constrained SNR and SINR maximization. First designed for beamforming and then channel estimation is applied to the beamformed system since in MIMO system CSI plays a major role. For these beamformed systems, channel estimation is applied and compared the performance of the system. The beamformed system with proper channel estimation (LSE and MMSE) gives a better result and here LSE estimation is preferred because paper concentrates on BER performance of the system.

A. Related Work

Multiple inputs multiple outputs orthogonal frequency division multiplexing (MIMOOFDM) is the dominant air interface for 4G and 5G broadband wireless communications. It combines multiple inputs, multiple outputs (MIMO) technology, which multiplies capacity by transmitting different signals over multiple antennas, and orthogonal frequency division multiplexing (OFDM), which divides a radio channel into a large number of closely spaced sub-channels to provide more reliable communications at high speeds. Multiple antenna techniques are considered as the promising technique for the high spectral efficiency. Beamforming for a multi-user MIMO interference channel, for communications between pairs of terminals. There are several pairs sharing the spectrum simultaneously. Each multi-antenna transmitter strives to direct its data to only one multi-element receiver. All other transmitters will make an interference. The use of an SINR constraint, where independent data streams are transmitted from a multi- antenna base station (BS) to several single-antenna mobile units. Joint transmit-receive optimization based on null space constraint was introduced in existing works. But none of these can be applied to the more complicated interference channel, which is the subject of this paper. [1, 5, 7]

In MIMO-OFDM channel estimation plays a major role and it is the estimation of the transmitted signal bits using corresponding received signal bits. While designing the channel estimator for wireless OFDM systems, two main problems will occur. The first problem is the arrangement of pilot information, in which pilot is the reference signal employed by both transmitters and receivers, whereas the second problem is the design of an estimator with excellent channel tracking ability. In this paper, an extensive review of different channel estimation methods used in MIMO-OFDM is discussed.

In this work only single-stream data transmission is considered because the signal processing operations are referring to beam-forming as a vector operator. Therefore, only single stream data transmission is considered. So multi-stream data transmission for each user, usually discussed in interference alignment (IA) design, is not used here. All users have multiple transmit and receive antennas. Joint transmit beamformer (Tx-BF) and receive beamformer (RxBF) design for minimum SINR maximization in a MIMO interference channel system has been proven to be a strongly NP-hard problem. Recently, a joint leakage interference (LI) minimization and maximization of the individual signal powers (SPs) and SINRs was reported using an optimization approach with a fixed point method. The numerical results revealed that the joint LI-SP-SINR problem has superior performance compared to the max-min SINR problem[7].

Paper proposed three new beam-forming designs. First, a constrained SNR maximization is sought in which the Tx-BFs for all the users are acquired by deploying the null-space of an appropriate channels matrix (described below).This null-space assignment for Tx-BFs eliminates one term of interference at each receiver. The remaining interference terms at each receiver can be eliminated by means of orthogonal vectors. The Rx-BF of each user, in this case, has a closed form solution if its norm is one. The second case is joint Tx-Rx beamformer design for constrained SNR maximization where only the Rx-BF at each receiver terminal nulls out all the interference. This problem leads to a multi-objective optimization which can be solved iteratively because it has guaranteed convergence. The third case is joint constrained SNR and SINR maximization [3]. This problem has a solution because its corresponding vector field is non-expansive. It can be considered as a new formulation for LI-SP-SINR. It is noted that multipath diversity gain for OFDM systems can also be obtained by using a multi-tap receive FIR filter. All of these new contributions come together in a new method for designing and deploying beamformers for multi-user systems. The details of the communications protocol to share the channel between sounding; interchanging of channel information between the terminals; setting the modulation and coding: setting the data payload size and scheduling; are not addressed here (such protocols are not yet developed), in order to focus on the beamforming problem [2,5].

II. SYSTEM MODEL

Beam-forming or spatial filtering is a signal processing technique used in sensor arrays for directional signal transmission or reception [1].This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beam-forming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity. The improvement compared with omnidirectional reception/transmission is known as the receive/transmit gain (or loss). Beamforming can be used for radio or sound waves. It has found numerous applications in radar, sonar, seismology, wireless communications, radio astronomy, acoustics, and biomedicine. Adaptive beamforming is used to detect and estimate the signal-of-interest at the output of a sensor array by means of optimal (e.g., least-squares) spatial filtering and interference rejection. If CSI is available both at the transmitter and the receiver, MIMO systems can benefit from significant diversity and coding gains by using beam-forming. CSI can be obtained at the transmitter by using a feedback channel. One restriction is that the delay introduced by the feedback channel must be shorter than the coherence time of the wireless channel [9].

A. Proposed beam forming design

The paper presents three beamforming design cases.

1. A constrained SNR maximization: Tx-BFs for all the users are acquired by deploying the null-space of an appropriate channels matrix (described below). Null-space assignment for Tx-BFs eliminates one term of interference at each receiver. The remaining interference terms at each receiver can be eliminated by means of orthogonal vectors.

2. Joint Tx-Rx beam-former design for constrained SNR maximization: Only the Rx-BF at each receiver terminal nulls out all the interference. This leads to a multi-objective optimization which can be solved iteratively because it has guaranteed convergence.

3. Joint constrained SNR and SINR maximization.

This problem has a solution because its corresponding vector field is non-expensive. It can be considered as a new formulation for LI-SP-SINR. For these three cases, the minimum required number of antennas is derived as a part of the formulation required feedback rates are computed for each approach and compared with those of existing beamforming schemes. The proposed methods are also computationally simpler. To improve the digital communications error performance the system formulation can include a pre-coder matrix. It includes before the transmit beamformer and a sphere decoder (SD).This is to allow multipath diversity gain from the OFDM system. This pre-coder is a fixed matrix that does not need instantaneous channel knowledge. It does need knowledge of some channel characteristics for optimal deployment. Multipath diversity gain for OFDM systems can also be obtained by using multi-tap receive FIR filter [1, 3,4].

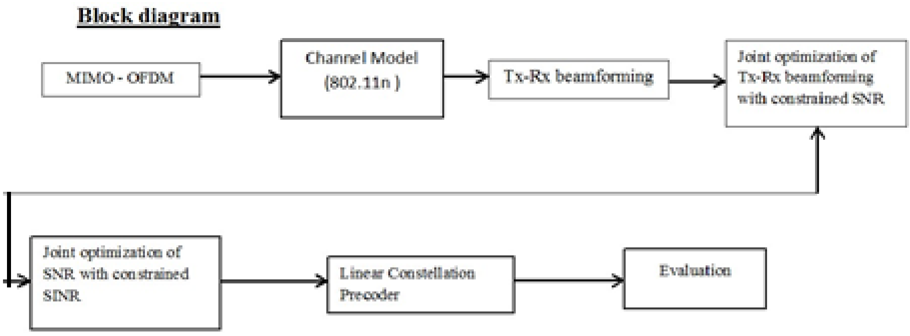
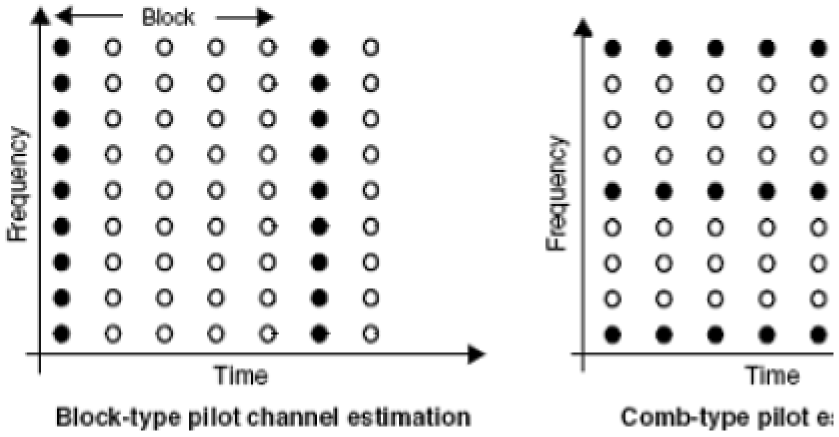


Figure 1: Block diagram

The advantages of this proposed algorithm are
a) Higher SNR
b) Interference avoidance and rejection
c) Higher network efficiency networks

III. CHANNEL ESTIMATION

The two basic channel estimations in OFDM systems are illustrated in Figure 2 [3]. The first one, block-type pilot channel estimation, is developed under the assumption of slow fading channel, and it is performed by inserting pilot tones into all subcarriers of OFDM symbols within a specific period. The second one, comb-type pilot channel estimation, is introduced to satisfy the need for equalizing when the channel changes even from one OFDM block to the subsequent one. It is thus performed by inserting pilot tones into certain subcarriers of each OFDM symbol, where the interpolation is needed to estimate the conditions of data subcarriers [3].



The figure shows the comparison between two types. MIMO channel requires estimation of Nt × Nr sub-channels, moreover this great number, difficulties also is in inter-symbols interferences generating by Nt emission antennas. A simple solution to this problem is to estimate, in succession different emission antenna channels. Nr channels for each emission antenna are estimated using pilot sequence so other antenna doesn't send anything. Despite its simplicity, this technique has many problems. First, decreasing efficiency when antenna number increases. The result is an important intolerable delay for wireless systems especially for joint beamforming systems where channel estimation in reception must be sent to emission part .moreover such schema needs synchronization .Another proposition consists in sending OFDM pilot sequences simultaneously and to modulate some sub-carriers (see figure 3).For instance, in a system with N_t=3, each emission antenna modulate one carrier per three. So orthogonality between subcarriers is maintained .for LS estimation case, we must send N_t blocks at least either interpolate modulated carriers is to send simultaneously blocks modulating all carriers using pilot symbols interfering as little as possible [10].

III. (a) Classification of Channel Estimation

In a wireless communication link, CSI provides the known channel properties of the link. This should be estimated at the receiver and usually fed back to the transmitter. Therefore the transmitter and receiver can have different CSI. The channel state information may be instantaneous or statistical. In instantaneous CSI, the current channel conditions are known, which can be improved by knowing the impulse response of the transmitted sequence. But statistical contains the statistical characteristics such as fading distribution, channel gain, spatial correlation etc… [8].

In fast fading systems where channel conditions vary rapidly under the transmission of a single information symbol, only statistical CSI is reasonable. But, in slow fading systems, instantaneous CSI can be estimated with reasonable accuracy. So channel estimation technique is introduced to improve the accuracy of received signal.

The radio channels in mobile communication systems are usually multi- path fading channels, which are causing inter-symbol- interference (ISI) in the received signal. To remove ISI from the signal many kinds of detection algorithms are used at the receiver side. These detectors should have the knowledge of channel impulse response (CIR) which can be provided by separate channel estimator [9]. Basic classification of channel estimation algorithm is shown below. They are training based, blind channel estimation or semi-blind channel estimation [12].

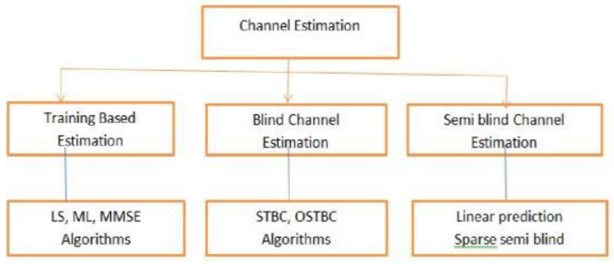


Figure2: Classification of Channel Estimation

a) Training Based Channel Estimation

This can be performed by either block type pilots or comb type pilots. In block type pilot estimation, pilot tones are inserted into all frequency bins within the periodic intervals of OFDM blocks. This estimation is suitable for slow fading channels. But in comb type pilot estimation, pilot tones are inserted into each OFDM symbol with a specific period of frequency bins. This type of channel estimation id very much suitable where the changes in OFDM block [11].

b) Blind Channel Estimation

It is carried out by evaluating the statistical information of the channel and particular properties of the transmitted signals. This blind channel estimation has no overhead loss and it is only suitable for slowly time-varying channels. But in training-based channel estimation, training symbols or pilots that are known to the receiver, are multiplexed along with the data stream for channel estimation [10].

c) Semi-Blind Channel Estimation

The semi-blind channel estimation algorithm is a hybrid combination of blind channel estimation and training-based channel estimation which utilizes pilot carriers and other natural constraints to perform channel estimation [10].

IV. PROPOSED CHANNEL ESTIMATION

Since beamforming is a spatial filtering, which improves system performance like SNR and BER. So designed system performs high SNR and low BER. A further modification is done with channel estimation which is obtained by channel state information (CSI). Detailed analysis of channel estimation is discussed later. The paper deals with least square error (LSE) channel estimation and minimum mean square error (MMSE) channel estimation. MMSE channel estimation gives good results in signal-to-noise-ratio (SNR), LSE is preferred.

V. LSE ESTIMATION

Consider a 2 × 2 MIMO system, represented as:

$$\begin{pmatrix} Y(0) \\ Y(1) \end{pmatrix} = \begin{pmatrix} X(0) & 0 \\ 0 & X(1) \end{pmatrix} \begin{pmatrix} h(0) \\ h(1) \end{pmatrix} + \begin{pmatrix} n(0) \\ n(1) \end{pmatrix}$$

$$Y = XH + n$$

Where X is a diagonal matrix, since assuming all subcarriers are orthogonal. H is the channel vector and n is noise vector and Y is the received signal. Assuming zero mean and variance of$\sigma 2$. Let $\hat{H}$ denote the estimate of channel H, the least square (LS) channel estimation method finds the channel estimate $\hat{H}$ in such a way that the following cost function is minimized:

$$J(\hat{H}) = \|Y - X\hat{H}\|^2$$

$$=(Y - X\hat{H})^H (Y - X\hat{H})$$

$$=Y^H Y - Y^H X\hat{H} - \hat{H}^H X^H Y + \hat{H}^H X^H \hat{H}$$

By setting the derivative of the function with respect to $\hat{H}$ is zero, gives the solution to the LS channel estimation as:

$$\hat{H}_{LS} = (X^H X)^{-1} X^H Y = X^{-1} Y$$

Since X is assumed to be diagonal due to the ICI-free condition, the LS channel estimate $\hat{H}LS$ can be written for each subcarrier as:

$\widehat{H}_{LS}[K] = \frac{Y[K]}{X[K]}$, K=0, 1, 2, 3, ………………., N-1.

The mean square error (MSE) of this LS channel estimation is given as:

$$MSE_{LS} = \mathrm{E}\left(H - \widehat{H}_{LS}\right)^{H}(H - H_{LS}$$

$$= \mathrm{E}(H - X^{-1}Y)^{H}(H - X^{-1}Y)$$

$$= \frac{\sigma_n^2}{\sigma_X^2}$$

It is clear that the above equation is inversely proportional to the SNR, which implies that it may be affected by noise, but due to its simplicity, LS method has been widely used for channel estimation. MMSE estimator gives a better result than LSE but it will affect badly on BER and increase SNR performance. Paper concentrated on BER performance so MMSE is not used.

PERFORMANCE REVIEW

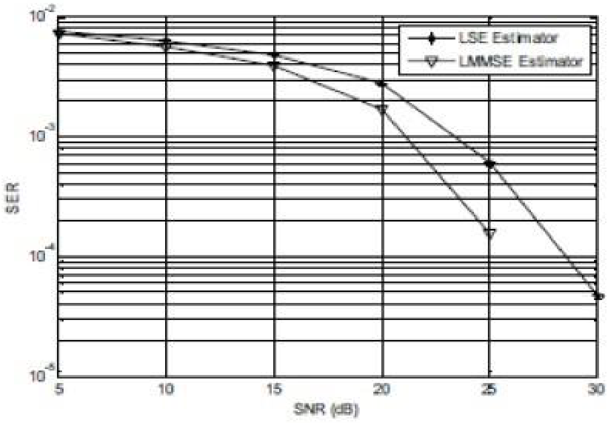


Figure 3: Channel Estimation using LSE and MMSE

IV. SIMULATION RESULTS

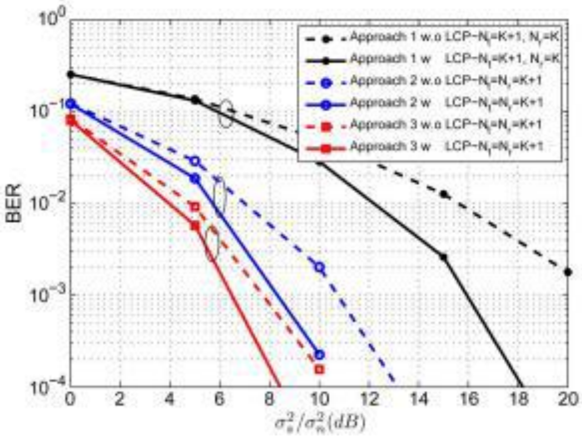


Figure 4: BER Performance of three approaches

The graph shows BER performance of three beamforming techniques individually and with LSE channel estimator.

VI. CONCLUSION AND FUTURE WORK

Three beamformers are designed and interference is eliminated from the TxRx beamformers .After designing the three beamforming evaluated the BER performance with and without using LCP .From the BER performance, it is found that the third approach is better than the rest two approach and it performs the least square approach and computational time is low. The second approach requires less feedback than third .It can achieve multipath diversity by applying LCP matrix. By applying LCP matrix improves the error performance in strongly idealized channels and still improve the error performance.

For improving the performance of the system, Channel estimation for MIMO-OFDM is widely studied. Two estimators are usually considered: LS and MMSE. After designing the LSE estimator individual performance is evaluated and also the combined beamforming effect is verified.

VII. ACKNOWLEDGEMENT

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