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MULTIUSER MIMO OFDM INTERFERENCE CHANNELS WITH JOINT BEAMFORMING

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ABSTRACT

In a multiuser multiple input and multiple output - orthogonal frequency division multiplexing channel there is correspondence over channel subjected to co-channel interference. Synchronisation is performed between the transmit antennas and receive antennas through beamforming applied in time domain using zero forcing beamforming technique that reduces interference, time delay making it a time tolerant network, increases the number of users in the channel and with an equaliser that amplifies the channel limit. A calculation is performed that amplifies the SINR furthermore upgrades the total rate limit.

Index Terms: MIMO-OFDM, synchronisation, zero forcing beamforming, equaliser, SINR, sum rate(rate limit).

I. INTRODUCTION

OFDM is being widely used in wireless communication systems. For growing voice and data services, it raises a higher demand of the transmission rate, transmission performance and data throughput. To achieve this, it is not enough only to use more spectrum resources, the space resources of the wireless signal should be used as well. That is using multiple antennas to transmit and receive the signal. Due to scattering in the wireless communication environment, reflection and diffraction caused by the multipath fading is a major factor in the deteriorating performance of wireless communication systems. For communications between sets of terminals where several sets share the same spectrum all the while beamforming is used [1]. Every transmitter has information to send to only one receiver in these channels, which additionally observes interference from the alternate transmitters in the system [2]. An array of multiple antennas in the spatial dimension can be viewed as an additional framework besides the traditional transfer capacity and power. Based upon the number of antennas and their relative position in space large performance gains are conceived. These gains however come at the cost of increased hardware complexity that makes the antenna arrays restrictive. Antenna arrays will be conveyed only at the base stations while the mobile terminals are outfitted with single antennas in this case. Hence by processing the antennas at the base stations coherently, beams are formed and beamforming is applied to both uplink and down link [3]. For both the communication links, beamformers can be adapted to match the current

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propagation characteristics. To this end, the channel conditions of all clients are thought to be known at the base station. The spectral efficiency in uplink can be optimized by independently adjusting nonlinear receivers (beamforming with successive interference cancellation) and in downlink the beamformers spread the signals over the antenna array like linear pre-equalizers prior to transmission [4].

Multipath propagation in general brings about channel fading, which is viewed as an unsafe factor for wireless communication. Nonetheless, research demonstrates that multipath transmission in a MIMO system can be of great help to the wireless communication. All the performance change and the capacity measures are clearly based on channel state information. The huge part of MIMO-OFDM system is the channel estimation. Therefore as an initial state the MIMO-OFDM channel estimation is performed. Synchronisation by beamforming operation for the signal processing is taken as a vector operator. To keep up closeness with the standard MU-MIMO system, the joint beamforming vectors are set using the traditionalistic MU-MIMO zero-forcing beamforming (ZFBF) and are further updated to maximize the total energy of the system and guarantee the signal to interference plus noise ratio (SINR) constraints. Interference and time delay is reduced thereby making the system a time tolerant one. The use of equalizer at the receiver end renders an appropriate frequency response and increased channel capacity. Maximization of SINR in [5] and [6] was dealt for a particular user which has multiple transmit and receive antennas, while the other user as an interferer has single transmit and receive antenna but in here all the users have multiple transmit and receive antennas.

II. MIMO-OFDM

Wireless communication systems in general use Single Input - Single Output (SISO) where only one transmit antenna (Tx) and one receive antenna (Rx) is used for transmission. For better results at the receiver additional antennas can be utilized at the transmitter and receiver. In today's world this scenario is presumably going to change with the evolving approach of Multiple Input - Multiple Output (MIMO) communication systems. For the most part, MIMO procedures have three classifications. Firstly it uses the extending of spatial diversity to upgrade the power capacity. Secondly the classification intends to expand the limit by utilizing layered strategy. At last, by taking in the properties of the transmission channel examines the coefficient matrix and uses these analysed unitary matrices as filter in transmitter and receiver to improve the capacity.

The multiple antennas and channels used in the MIMO system's transmitter and receiver bring about better performance. The serial data symbols from the transmitter are sent in time domain to the receiver and the received symbols are recovered through a combination of space-time detection technologies [7]. Keeping in mind the goal to ensure proper separation of the data symbols, the antennas must be isolated sufficient enough to prevent large correlation between the received signals.

OFDM is a multi-carrier modulation of the sub-carriers. In OFDM, the channel is divided into a number of orthogonal sub-channels and the high speed data signal which is serial is converted into parallel low speed sub-streams. These sub-streams are modulated on each sub-channel to be transmitted. OFDM is effective against frequency selective fading and Inter Symbol Interference (ISI). Since orthogonal sub-carriers are using as sub-channels, the spectral efficiency has been greatly improved. Our proposed method is computationally simpler than [8], [9] and [10] where linear precoding and interference alignment operations were carried out for interference suppression [8], [10] and interference reduced through mean square error (MSE) criterion [9]. We use optimal linear minimum mean square error (OLMMSE) to maximise the sum rate capacity and SINR.

III. SYSTEM MODEL

The MIMO interference channel model is as follows considering a K-user MIMO interference channel as in Fig.1, with K Tx-Rx pairs. A wireless channel interfaces every receiver to every transmitter, except a given transmitter only intends to have its signal decoded by a single receiver. While the wireless signal travels from the transmit antenna to the receive antenna, the characteristics of the signal changes because of the following factors: 1) the distance between the two antennas, 2) the path(s) taken by the signal and 3) the environment (building and other objects) around the path [11]. The effects of the channel are characterized by a linear response.

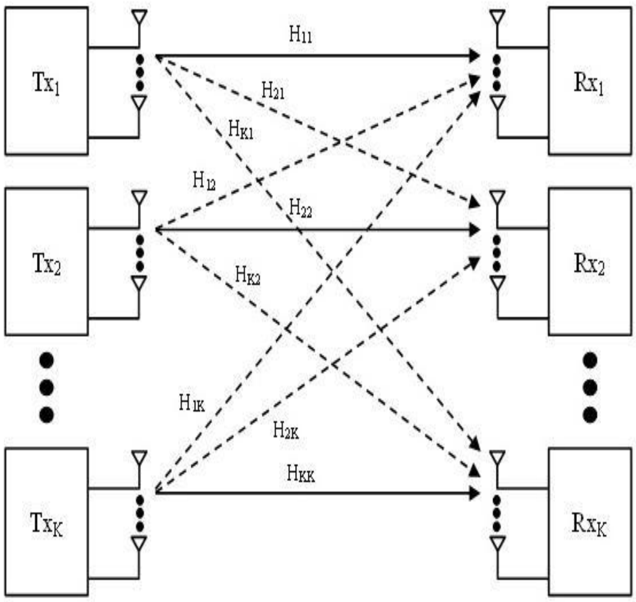

Fig. 1. MIMO Interference channel

A MIMO-OFDM interference channel taken with an equalizer as illustrated in Fig. 2. In frequency domain, the received signal y and the transmitted signal x can be expressed as,

$$y = Hx + n \qquad (1)$$

where H denotes the channel response and n denotes the noise. Considering an additive white gaussian noise (AWGN) channel with input binary bits from the Tx, in the signal model (1) yields a received OFDM signal in time domain as,

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$$y(t) = H(t)*x(t)+n(t) \quad (2)$$

Each high bit stream is converted to a low bit stream and is segmented. A major advantage of OFDM technology here is that Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) is used for the implementation of demodulation and modulation of orthogonal sub-channels. For the N point FFT operation, we need N×log(N) complex multiplications, instead of N^2, which requires a straight forward implementation. In this section, the complexity of the frequency-domain architecture is reduced by means of the four time-domain equivalent properties such as

1. Time-Domain Phase Rotation / Frequency-Domain Cyclic Shifting,

$$F^{-1}\{X[(k-l)_N\} = x[n].\exp\left\{\frac{j2\pi nl}{N}\right\}, \quad L = 0,1,\ldots,N-1 \quad (3)$$

2. Time-Domain Cyclic Shifting / Frequency-Domain Phase Rotation,

$$F^{-1}\left\{X[k].exp\left\{\frac{-j2\pi k\omega}{N}\right\}\right\} = x[(n-\omega)_N], \quad \omega = 0,1,\ldots,N-1 \quad (4)$$

3. Time-Domain Complex Conjugate of Time-Reversed Signals / Frequency-Domain Complex Conjugate

$$F^{-1}\{X^*[k]\} = x^*[(-n)_N] \quad (5)$$

and 4. Time-Domain Signal Reversal / Frequency-Domain Sub-carrier Reversal.

$$F^{-1}\{X[(-k)_N]\} = x[(-n)_N] \quad (6)$$

In addition, a time-domain repetition property is introduced in order to further reduce the computational complexity. Note that all of the operations described in this section (both time domain and frequency-domain) are performed on the sub-carriers of the same set.

The implementation of cyclic prefix acts as a buffer where the previous symbol data are stored. The Rx carefully excludes the unwanted overlapped data from the previous symbols.

$$s(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} x_k\, e^{j2\pi f_k t}, \quad 0 < t < NT \quad (7)$$

where in (7) Δ is the time period of the OFDM signal s(t). The length of the cyclic prefix Δ is chosen such that $\Delta > \Delta_h$. The received OFDM signal taken over the interval [0, NT] ignoring any noise that is present hence becomes,

$$r(t) = s(t) * h(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} H_k x_k e^{j2\pi f_k t}, \quad 0 < t < NT \quad (8)$$

where in (8),

$$H_k = \int_0^{\Delta_k} h(\tau)\, e^{j2\pi f_k \tau}\, d\tau$$

is the Fourier transform of h(t) at frequency f_k. The magnitude of the received bits their mean value are calculated and plotted.

IV. SNR MAXIMIZATION

The use of SINR constraint in [12] exploited the uplink-downlink SINR duality. The joint transmit and receive beamformers (Tx-BF & Rx-BF) for minimization of the SINR maximization proved to be a NP-hard problem [13] also the joint Tx-Rx optimisation was introduced in [14] for null space constraint. In this paper all the K users have N_t transmit antennas and N_r receive antennas and all use the P subchannels. The Tx-BF for the *i*th user at the *p*th subcarrier are denoted as $v_i(p) \epsilon\, C^{Nt*1}$ and the Rx-BF are denoted as $u_i(p) \epsilon\, C^{Nr*1}$ for $i \epsilon$ {1,…,K} and $i \epsilon$ {0,…,P-1}.

$$\mathrm{SINR}_i = S_i / (\textstyle\sum_{j \neq i}^{K} |I_j|^2 + N_i) \qquad (9)$$

where, $S_i = u_i^H H_{ii} v_i v_i^H H_{ii}^H u_i$, $I_j = u_i^H H_{ij} v_j$ and $Ni = \sigma_{ni}^2 u_i^H u_i$ ($\sigma_{s\ i}^2 = 1$). The maximization of SNR for *i*th term is,

$$\max_{u_i, v_i} \mathrm{SNR}_i = S_i / N_i \qquad \text{such that } I_j = 0 \quad j \neq I \qquad (10)$$

for Kϵ {2(n+1):nϵ N} where N is the positive integers. v_i is obtained by,

$$v_i = N(H_{K+1-i,i}) \qquad (11)$$

where

$$N(A) \equiv \{x | Ax = 0, \|x\| = 1\} \qquad (12)$$

(12) is an orthonormal basis function for null space of A. For Kϵ {2n+1:nϵ N}, v_i is obtained by,

$$v_i = \begin{cases} N(H_{K+1-i,i}) & \text{if} \quad K+1-i < i \\ N(H_{K,i}) & \text{if} \quad K+1-i = I \\ N(H_{K-i,i}) & \text{if} \quad K+1-i > i \end{cases} \qquad (13)$$

from (11) or (13) $H_{1,K} v_K = 0$. Now we find the value of u_i to maximize SNR while suppressing the remaining K-2 interference terms. Joint leakage interference minimization and maximization of SINR and individual signal powers was studied in [15].

To further enhance the implementation of digital communication without compromising on the sum rate performance, the system includes a precoder matrix before the Tx-BF and the decoder following the Rx-BF. This allows multipath diversity gain from the OFDM system [16] and this precoder being a fixed matrix needs no instantaneous channel knowledge but some knowledge about the channel characteristics [17]. Joint Tx-BF and Rx-BF are designed for the SNR maximization for the first user problem is summarised as,

$$\min_{v1} \mathcal{J} = -v_1^H(G_1 + G_2)v_1 \quad \text{such that } \|v_1\| = 1 \tag{14}$$

where,

$$G1 \equiv H_{1,1}^H[N(C_1)]_1 [N(C_1)]_1^H H_{1,1}$$

$$G2 \equiv H_{1,1}^H[N(C_1)]_2 [N(C_1)]_2^H H_{1,1}$$

are the joint constrained SNR and the unique global solution of (14) is

$$v_1 = w_{max}(G_1+G_2) = l_1(v_2,\ldots,v_K) \tag{15}$$

In general, $v_i = l_i(v_1,\ldots,v_{i-1},v_{i+1},v_K)$ where l_i is the maximum normalised eigen vector function.

V. SIMULATION AND RESULTS

TABLE I : Simulation Parameters

Symbol	Name	Value
P	Number of subcarriers	52
K	Number of users	3,4
N_r	Number of receiver antenna per user	K,K+1
N_r	Number of transmitter antenna per user	K+1
L+1	Channel length	9
L_{CP}	Cyclic prefix	10
$\mathcal{J}$	Rotation matrix rank	8
N	Iterations for EAO	16

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Here numerical values are plotted for validating the results. As QPSK is the simplest approach in MIMO-OFDM, all the users make use of this for BER performance evaluation. With maximum likelihood decoding and uniform power delay maximum multipath diversity for linear constellation precoding (LCP)-OFDM is achieved.

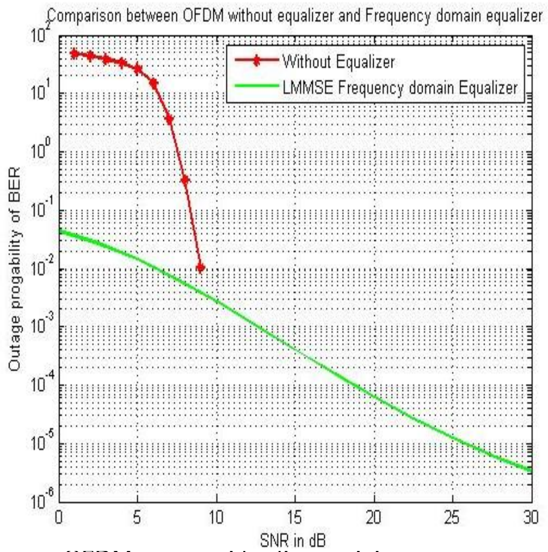

Fig. 3. Comparison between an OFDM system with a linear minimum mean square error (LMMSE) frequency domain equaliser and without an equalizer

From Fig. 3, comparison between an OFDM system with a linear minimum mean square error (LMMSE) frequency domain equaliser and without an equalizer is studied. It is clearly seen that without an equalizer maximum SNR ranges to about 9db whereas with an equaliser it can be extended to almost 32db also the graph tends to be a linear one when compared to the one without an equaliser.

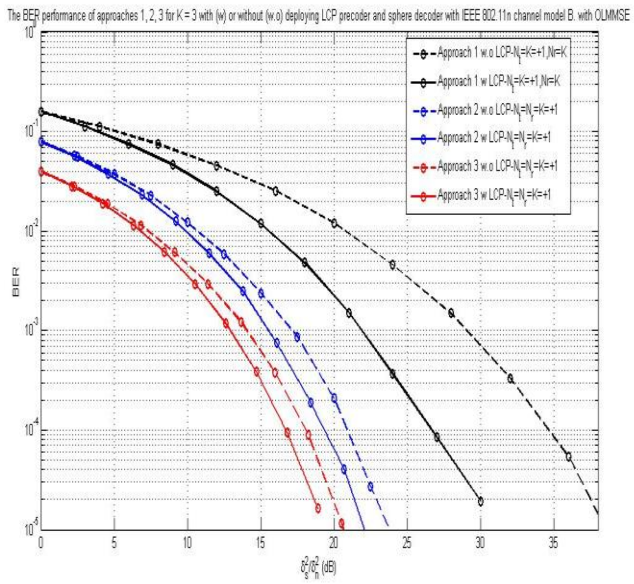

Fig. 4. BER performance of approaches 1, 2 and 3 for K=3 with (w) and without (w.o) LCP and sphere decoder with IEEE 802.11n channel model B

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Performance of bit error rate of the optimized beamformers versus average SNR is shown in Fig.4. Three approaches stated in the legend are as follows: approach 1 is Rx-BF design for SNR maximization when Tx-BFs are fixed; approach 2 is joint Tx-Bf and Rx-BF design for SNR maximisation; approach 3 is the Tx-BF and Rx-BF design for instantaneous SNR and SINR maximization. All the above mentioned three approaches with and without the LCP matrix ϕ is observed. Here $\phi = I_{PxP}$ means there is no change at the Tx side from the LCP matrix and at the Rx side performance terms such as symbol-wise and frame-wise detection have the same results. Using LCP matrix improves the system performance to a great extent.

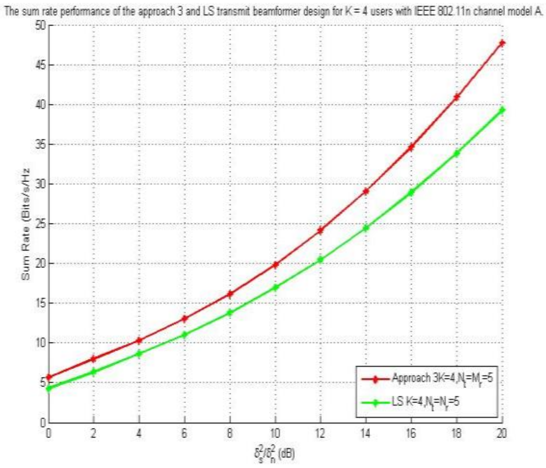

Fig. 5. The sum rate performance of the approach 3 and LS Tx-BF design for K=4 users with IEEE 802.11n channel model A.

The computational complexity and BER performance of the existing system such as ZF, LI and sum rate are compared with the proposed methods are illustrated in Fig. 5. It has lower BER and better sum rate performance.

VI. SUMMARY AND CONCLUSION

We have thus designed a simple MIMO – OFDM wireless system simulated in MATLAB in this paper. The proposed method can fairly handle multiple antennas at the transmit end and at the receiver end. It is shown that joint SNR and SINR maximization outperforms the LS beamforming design with lower computational time. Using LCP matrix in strongly idealized channel improves the error performance and our simulation illustrates that error performance is greatly improves for a realistic IEEE 802.11n channel through the addition of LCP matrix. The results of this paper brings out the capability of extracting multipath diversity, algorithmic simplicity and better sum rate capacity of the MIMO-OFDM interference channel.

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