

Multi-Objective Optimization Contingent on Subcarrier-Wise Beamforming for Multiuser MIMO-OFDM Interference Channels

R. Vedhapriya Vadhana, Ruba Soundar, K. G. Jothi Shalini

Abstract—We address the problem of interference over all the channels in multiuser MIMO-OFDM systems. This paper contributes three beamforming strategies designed for multiuser multiple-input and multiple-output by way of orthogonal frequency division multiplexing, in which the transmit and receive beamformers are acquired repetitiously by secure-form stages. In the principal case, the transmit (TX) beamformers remain fixed then the receive (RX) beamformers are computed. This eradicates one interference span for every user by means of extruding the transmit beamformers into a null space of relevant channels. Formerly, by gratifying the orthogonality condition to exclude the residual interferences in RX beamformer for every user is done by maximizing the signal-to-noise ratio (SNR). The second case comprises mutually optimizing the TX and RX beamformers from controlled SNR maximization. The outcomes of first case is used here. The third case also includes combined optimization of TX-RX beamformers; however, uses the both controlled SNR and signal-to-interference-plus-noise ratio maximization (SINR). By the standardized channel model for IEEE 802.11n, the proposed simulation experiments offer rapid beamforming and enhanced error performance.

Keywords—Beamforming, interference channels, MIMO-OFDM, multi-objective optimization.

I. INTRODUCTION

DIFFICULTIES for broadband wireless contact skills such as mobile internet, multi-broadcasting amenities given by communication schemes are promptly mounting during the most recent years. MIMO structures [18] guarantee a diversity benefit relational to the product of the amount of transmit and receive antennas. Multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) [20] shows the simple equalization of OFDM modulation with the capacity, diversity and array gain [2]-[4]. In the existence of interference from all users' transmitters [23], each multi-component transmitter attempts to direct its information to only one multi-component receiver [1] and it is altered from the multiuser uplink and downlink beamforming [5], [6]. By manipulating uplink and downlink SINR duality, unique

optimization complications can be decayed into modest optimization glitches [7]. Interference alignment (IA) is recycled to realize supreme degrees of freedom in the interference network [12]. The difficulties of pre-filtering and post-filtering in multiuser MIMO communication [24] by means of SDMA is labelled in [6]. It practices Combined Transmit-Receive maximization centred on null space compulsion. It cannot be functional for supreme sophisticated interference passages. The outline is established precisely for spatial multiplexing and realistic to multiuser MIMO-OFDM classifications with asynchronism among users in addition to distinct user MIMO-OFDM schemes is illuminated in [9]. The extended work discusses the intervention dominance routines the IA in [8] but multi-stream data communication for every user is not used here. The method used in [8] customs subjective sum rate maximization method. To overwhelm the power competent multiuser beamforming, [8] uses uplink and downlink beamforming explained in [11]. Symbol-wise beamforming is used to diminish the intricacy by carrying out beamforming in time domain as designated in [13]. It is clear that there are numerous diverse methodologies to the beamforming complications. This paper presents different beamforming approaches to advance the performance in wireless communication systems. This paper grants three beamforming design cases. First, a controlled SNR maximization is pursued in which the TX-BF for all users are developed by arraying the null-space of a suitable channel matrix (mentioned further down). This null-space consignment for TX-BFs discards one span of interference at every receiver. The residual interference terms at each receiver can be excluded by means of orthogonal vectors. In this event, it has secure-form solutions for each RX beamformer. The second case is collective TX and RX beamformer strategy for controlled SNR maximization. Here, RX-BF at every terminal cancels all the interference. The third case is collective controlled SNR and SINR maximization. For these three designs, the measure of construction derived the least number of antennas requisite for the systems. The proposed models are computationally modest than [8], [10], [12] and [21]. The contributions of this paper comprise of: 1) Secure form solutions for various cases of the combined beamformers strategies in the N-user MIMO interference channel [16]; 2) The inception for least number of antennas requisite for these solutions; 3) Simulated performance results by means of typical multipath channel representation screens the performance of the systems in further genuine conditions than

R. Vedhapriya Vadhana is working as Assistant Professor and Head of the Department in Francis Xavier Engineering College, Tirunelveli, TamilNadu, India (e-mail: vedhapriya.vadhana@gmail.com).

Ruba Soundar is Professor in Computer Science and Engineering Department of P.S.R. Engineering College, Sivakasi, Tamil Nadu, India (e-mail: rubasoundar@gmail.com).

K. G. Jothi Shalini is pursuing M.E., degree with Electronics and Communication Engineering in Francis Xavier Engineering College, Tirunelveli, Tamil Nadu, India (Phone: 9578067762, e-mail: jothishalini25@gmail.com).

formerly mentioned; 4) A new formulation for the standard least-square (LS) solution and simulation outcomes for all accessible beamformer design [19] cases.

The mathematical notation is as follows: Column matrices and vectors are represented by boldface upper and lower case letters one-to-one. Superscripts H and T provide the complex conjugate transpose and transpose, separately, and a^* signifies the value of a , and does not symbolize the complex conjugate of a . The null space of matrix M is denoted by $\mathcal{N}(M)$. $x_{\max}(M)$

is the standardised eigenvector of matrix M that resembles to the maximum eigenvalue of M . x and y are orthogonal if $x^H y = 0$. J_p is the $P \times P$ identity matrix. $M(:,i)$ is the i th column of matrix of M in MATLAB notation, i.e., $M(:,i) = [M]_i$. For $M \in \mathbb{C}^{m \times n}$, $m = \text{size}(M,1)$ and $n = \text{size}(M,2)$. The Euclidean standard of a vector y is $\|y\|$. Lastly, $y \in \mathbb{C}^n \setminus 0$ means that vector y is a non-zero vector through complex entries. Expected value is denoted by $E\{\cdot\}$.

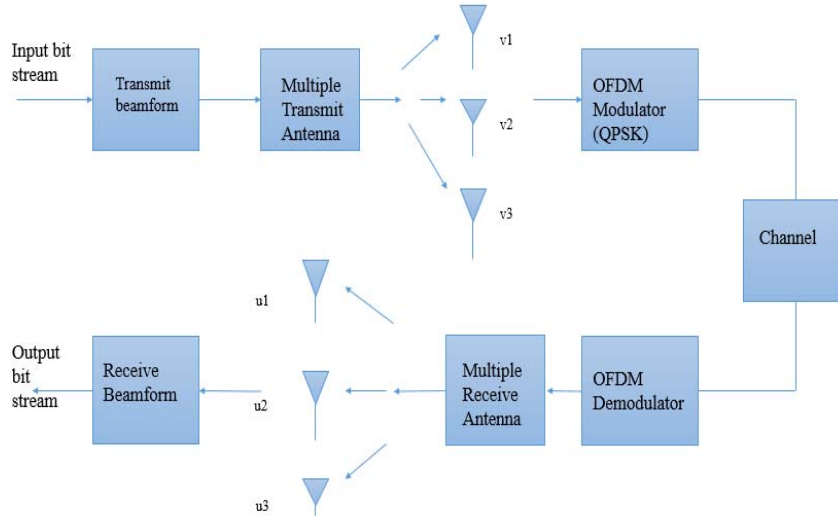


Fig. 1 Simple structure of MIMO-OFDM based on Beamforming

II. SYSTEM OVERVIEW, GLITCHES FORMULATIONS AND THEIR SOLUTIONS

Let us consider the N -user interference channel with K_t transmit antennas at transmitter t and K_r receive antennas at receiver r . Every user directs the stream of information by means of OFDM through R subcarriers. This is identified as MIMO-OFDM, which is an extensively arrayed communication technique in commercial wireless standardized channels such as IEEE 802.11n [22]. The transmission condition as it conveys to the model is described as follows. There are N pairs of multi-projection terminals which remain attempting to share instantaneously the spectrum in time and space. The standardized channel is demonstrated as 1) a selected delay line $(L+1)$ taps conferring to the IEEE 802.11n model or else 2) a particular-tap flat fading channel using flawless spatial correlation matrix. In this paper, the first model explains both the MIMO-OFDM formation. The second model is used merely to contrast the performance of surviving approaches [22] with our three proposed strategies. The standardized model of IEEE 802.11n adopts the following properties [14]: i) The power azimuth spectrum (PAS) in addition the power delay profile (PDS) exist dissociable. ii) The spatial correlation and temporal correlation are exhibited independently. iii) Every tap is shown via the Kronecker model.

Here, we erect for optimizing the equivalent system capacities, and then compute related digital performance after

optimization. The minutiae of the system given as follows. The system consists of N users having K_t transmit antennas and K_r receive antennas and all users exploit R subcarriers. The calculation in this division adopts $N \geq 3$; the case for $N = 2$ is distinct and it is shown below.

From Fig. 1, the TX beamformer for i th user at r th subcarrier is inscribed as $\mathcal{P}_i(r) \in \mathbb{C}^{K_t \times 1}$, and likewise the RX beamformer for i th user at r th subcarrier is given as $\mathcal{Q}_i(r) \in \mathbb{C}^{K_r \times 1}$ for $i \in \{1, 2, \dots, N\}$ then $r \in \{0, 1, 2, \dots, R-1\}$. s_i is the input symbol stream of i . the symbol stream is given by $\tilde{s}_i \triangleq \Theta[s_i(0), \dots, s_i(R-1)]^T$ then the output of TX beamformer is given as $\mathcal{P}_i(r)\tilde{s}_i(r)$ from which $\|\mathcal{P}_i(r)\| = 1$ and $\tilde{s}_i(r)$ r th vector of $\tilde{s}_i$. to make the computation simple, assume $\Theta = T_{R \times R}$. So, in this special case $\tilde{s}_i(r) = s_i(r)$. The frequency selective channel from the μ th transmit antenna of the i th transmitting user and v th receive antenna of u th receiving user is given by $f_{v\mu}^{u,i}(l)$ where $v \in \{1, 2, \dots, K_r\}$, $\mu \in \{1, 2, \dots, K_t\}$, and $r \in \{1, 2, \dots, N\}$. By assuming faultless OFDM timing synchronization, then after the exclusion of cyclic prefix L_{cp} and after the Fast Fourier Transform, the received signal vector is given as,

$$d_i(r) = \mathbf{F}_{i,i}(r)\mathcal{P}_i(r)s_i(r) + \sum_{l' \neq i}^N \mathbf{F}_{i,l'}(r)\mathcal{P}_{l'}(r)s_{l'}(r) + n_i(r) \quad (1)$$

From (1), the system at r subcarrier is $\mathbf{F}_{u,i}(r) \in \mathbb{C}^{K_r \times K_r}$. The entry of (v, μ) is derived as $[\mathbf{F}_{u,i}(r)]_{v\mu} \triangleq F_{v\mu}^{u,i}(r)$, so that

$$F_{v\mu}^{u,i}(r) := \sum_{l=0}^L f_{v\mu}^{u,i}(l) e^{-j2\pi r l / R} \quad (2)$$

From the kronecker model, the tap channel matrix is denoted as $\mathbf{F}_l^{u,i} = (\mathbf{U}_l^u)^{1/2} \mathbf{H}_l(\mathbf{U}_l^i)^{T/2}$ where, $f_{v\mu}^{u,i}(l) = [\mathbf{F}_l^{u,i}]_{v,\mu}$ and $\mathbf{H}_l \in \mathbb{C}^{K_r \times K_t}$ is the complex matrix with zero mean and unit variance entries. The $\mathbf{U}_l^u$ and $\mathbf{U}_l^i$ are the receive and transmit spatial correlation matrix and the value is specified as,

$$[\mathbf{U}_l^u]_{v,\mu} = \begin{cases} 1 & \text{for } v = \mu \\ \rho_{v,\mu}^{u,l} & \text{for } v \neq \mu \end{cases}$$

The probability density function $g^l(\phi)$ for IEEE 802.11n is modelled as laplacian distribution and specified as,

$$g^l(\phi) = \frac{1}{A} \sum_{c=1}^{C_c} \frac{n_c^l}{\theta_c^l} e^{-\frac{\sqrt{2}|\phi - \Omega_c^l|}{\theta_c^l}} \quad (3)$$

where, A is normalization factor ($\int_{-\pi}^{\pi} g^l(\phi) d\phi = 1$), C_c denotes the number of clusters, n_c^l is the average path gain for cluster c , θ_c^l indicates the angular spread for cluster, and Ω_c^l signifies path angle-of-arrival (AoA) from cluster. For both the channel models, the foremost emphasis is the beamformer design. Thus by applying the RX-BF to all subcarriers of all users, then it is streamlined as follows by dropping index r :

$$Q_i^H d_i = Q_i^H \mathbf{F}_{i,i} \mathcal{P}_i s_i + \sum_{i' \neq i}^N Q_i^H \mathbf{F}_{i,i'} \mathcal{P}_{i'} s_{i'} + Q_i^H n_i \quad (4)$$

To have good detection performance, designing of $\mathcal{P}_i$ and Q_i is important for all users in MIMO interference channels. Earlier work [15] exposed the resulting optimization:

$$\max_{\mathcal{P}_i, Q_i} \sum_{i=1}^N \log_2(1 + \text{SINR}_i)$$

The above equation does not have secure form solution.

$$\text{s.t.} \quad \begin{cases} Q_i^H Q_i = 1 & i = 1, \dots, N \\ \mathcal{P}_i^H \mathcal{P}_i = 1 & i = 1, \dots, N \end{cases} \quad (5)$$

in which it does not have secure-form solution for $\mathcal{P}_i$ and Q_i where, $\text{SINR}_i = S_i / (\sum_{j \neq i}^N |T_j|^2 + K_i)$, $S_i = Q_i^H \mathbf{F}_{i,i} \mathcal{P}_i \mathcal{P}_i^H \mathbf{F}_{i,i}^H Q_i$, $T_i = Q_i^H \mathbf{F}_{i,j} \mathcal{P}_j$ and $K_i = \sigma_{n_i}^2 Q_i^H Q_i$ ($\sigma_{n_i}^2 = 1$). Hence, in our paper the optimization problem is provided as:

$$\begin{aligned} \max_{Q_i, \mathcal{P}_i} \text{SINR}_i &= S_i / K_i \\ \text{s.t.} \quad T_j &= 0 \quad j \neq i \end{aligned} \quad (6)$$

which has the secure-form solutions for $\mathcal{P}_i$ and Q_i . To deal with the problem in (6), initially we assume that one

interference span is excluded before applying the RX beamformer. So, problem in (6) is condensed to a problem with Q_i being the only choice variable. But by designing the $\mathcal{P}_i$ and Q_i jointly demonstrates the secure-form solution for controlled SNR maximization. As a result, resolving controlled SNR maximization is more accessible than solving (5).

III. PROPOSED BEAMFORMING DESIGNS

A. Ideal Rx-Bfs for Controlled SNR Maximization While Tx-Bfs Are Known

In this case, the TX beamformers are originate from the null space of applicable set of channels, besides then the optimal RX beamformers are pursued. For $N \in \{2(n+1): n \in \mathbb{N}\}$, where $\mathbb{N}$ denotes the positive integers and the TX beamformer $\mathcal{P}_i$ is attained by,

$$\mathcal{P}_i = \mathbf{N}(\mathbf{F}_{N+1-i,i}) \quad (7)$$

where,

$$\mathbf{N}(\mathbf{A}) \triangleq \{\mathbf{y} | \mathbf{A}\mathbf{y} = \mathbf{0}, \|\mathbf{y}\| = 1\} \quad (8)$$

is an orthonormal basis for the null space of $\mathbf{A}$.

From (7), it is clear that, $\mathbf{F}_{1,N} \mathcal{P}_N = 0$. The following step is to determine Q_i , such that it exploits SNR of i th user though overwhelming the $N-2$ residual interference terms. To make the computation simple, it is taken that $E\{|s_i|^2\} = \sigma_s^2$ and $E\{n_i n_i^H\} = \sigma_n^2 T$. Thus, the optimization problem is represented by ρ for one receiver and the residual receivers can be acquired by similar procedures. The optimization problem is stated as,

$$\begin{aligned} \rho: \quad & \max_{Q_1 \in \mathbb{C}^{K_r \times 1}} Q_1^H \mathbf{F}_{1,1} \frac{\mathcal{P}_1 \mathcal{P}_1^H \mathbf{F}_{1,1}^H Q_1}{Q_1^H Q_1} \\ \text{s.t.} \quad & \begin{cases} Q_1^H \mathbf{F}_{1,2} \mathcal{P}_2 = 0 \\ Q_1^H \mathbf{F}_{1,3} \mathcal{P}_3 = 0 \\ \vdots \\ Q_1^H \mathbf{F}_{1,N-1} \mathcal{P}_{N-1} = 0 \end{cases} \end{aligned} \quad (9)$$

ρ is considered as the controlled SNR maximization done in both TX and RX beamformers. The tricky with the eigen solution arises through maximizing the relation of quadratic forms. On the other hand, the dissimilarity occurs in this case is ρ has constraints. So, it yields different solution. These constraints compel the interference for first user to be removed. To resolve ρ , Lagrangian function is required:

$$\mathcal{L}(\mathbf{y}, \xi) = -\frac{\mathbf{y}^H \mathbf{B} \mathbf{y}}{\mathbf{y}^H \mathbf{y}} - \sum_{i=1}^{N-2} \xi_i \mathbf{y}^H \mathbf{b}_i \quad (10)$$

where $\mathbf{y} = Q_1$, $\mathbf{B} = \mathbf{F}_{1,1} \mathcal{P}_1 \mathcal{P}_1^H \mathbf{F}_{1,1}^H$ and $\mathbf{b}_i = \mathbf{F}_{1,i+1} \mathcal{P}_{i+1}$.

The optimization problem ρ not only has global maximum but also has local maxima. The local maximum of ρ is denoted as y^{lcm} if

$$\begin{cases} \mathbf{B} \mathbf{y}^{\text{lcm}} = 0 \\ \mathbf{b}_i^{\text{H}} \mathbf{y}^{\text{lcm}} = 0 \end{cases} \quad (11)$$

The solution to $\mathbf{y}^{\text{lcm}}$ might be zero; however, the attention is in solutions where $\mathbf{y}^{\text{lcm}}$ is non-zero that is $\mathbf{y}^{\text{lcm}} \neq 0$. It is reminded that $\mathbf{B} \in \mathbb{C}^{K_r \times K_r}$ and $\mathbf{y}^{\text{lcm}} \in \mathbb{C}^{K_r \times 1}$. The number of unidentified parameters obtained by (11) for $\mathbf{y}^{\text{lcm}} \neq 0$ define the least number of antennas essential for optimization p.

For controlled SNR maximization, the least number of transmit and receive antennas are denoted as $\min(K_r) = N$ and $\min(K_t) = N + 1$, respectively. Therefore, the optimum RX-BF is in secure-form stages for controlled SNR maximization problem.

B. Combined Tx-Bf and Rx-Bf for Controlled SNR Maximization

In earlier case, the optimal secure-form RX-Bfs were obtained by (18), according to users in TX beamformers. In this case, the combined TX-BF and RX-BF are considered using controlled SNR maximization by using the elongated successive optimization (ESO), (see appendix) for multi-objective optimization.

The value of $\mathbf{H}_1$ and $\mathbf{H}_2$ for the channel $\mathbf{C}_n$ is specified as,

$$\begin{aligned} \mathbf{H}_1 &\triangleq \mathbf{F}_{n,n}^{\text{H}} [\mathbf{N}(\mathbf{C}_n)]_1 [\mathbf{N}(\mathbf{C}_n)]_1^{\text{H}} \mathbf{F}_{n,n} \\ \mathbf{H}_2 &\triangleq \mathbf{F}_{n,n}^{\text{H}} [\mathbf{N}(\mathbf{C}_n)]_2 [\mathbf{N}(\mathbf{C}_n)]_2^{\text{H}} \mathbf{F}_{n,n} \end{aligned}$$

and this is given for N users in MIMO-OFDM system model. The ESO algorithm organized for combined $\mathcal{P}_1$ and $\mathcal{Q}_1$ design for controlled SNR maximization.

TABLE I
ESO ALGORITHM FOR COMBINED SNR MAXIMIZATION FOR TX-BF AND RX-BF

1:	Set $M > 1$; $\mathcal{P}_n^{(0)}$ for $i=1, \dots, N$
2:	For $k = 0 : M-1$ do
3:	Compute $\mathbf{C}_n \triangleq [(\mathbf{F}_{n,u}^{\text{H}} \mathcal{P}_u^{(k+1)})^{\text{H}}; \dots; (\mathbf{F}_{n,s}^{\text{H}} \mathcal{P}_s^{(k+1)})^{\text{H}}] u, s \in \mathcal{N} \setminus \{n\}$
4:	$\mathcal{P}_n^{(k+1)} = x_{\max}(\mathbf{H}_1 + \mathbf{H}_2)$
5:	$Q_n = \sqrt{\frac{\mu_1}{\mu_1 + \mu_2}} [\mathbf{N}(\mathbf{C}_n)]_1 + \sqrt{\frac{\mu_2}{\mu_1 + \mu_2}} e^{-i\varphi} [\mathbf{N}(\mathbf{C}_n)]_2$
6:	Compute $\mathbf{H}_1$ and $\mathbf{H}_2$ for $\mathbf{C}_n$
7:	$\mu_1 = \mathcal{P}_n^{(M)\text{H}} \mathbf{F}_1 \mathcal{P}_n^{(M)}$, $\mu_2 = \mathcal{P}_n^{(M)\text{H}} \mathbf{F}_2 \mathcal{P}_n^{(M)}$
8:	End for

The combined controlled SNR maximization problem for first user is given by,

$$\mathcal{H} : \max_{\mathcal{P}_1 \in \mathbb{C}^{K_t}, \mathcal{Q}_1 \in \mathbb{C}^{K_r}} \mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} \mathcal{P}_1 \mathcal{P}_1^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1 \quad (12)$$

The above problem has secure-form solution if $K_r = N + 1$. The problem of finding optimal TX-BF for first user is stated as:

$$\begin{aligned} \min \mathcal{J}_1 &= -\mathcal{P}_1^{\text{H}} (\mathbf{H}_1 + \mathbf{H}_2) \mathcal{P}_1 \\ \text{s.t. } \|\mathcal{P}_1\| &= 1 \end{aligned} \quad (13)$$

where the channel matrix is given as, $\mathbf{C}_1 \triangleq [(\mathbf{F}_{1,2} \mathcal{P}_2)^{\text{H}}; \dots; (\mathbf{F}_{1,N} \mathcal{P}_N)^{\text{H}}]$ and the value of φ is given by $\varphi \triangleq \angle [\mathbf{N}(\mathbf{C}_n)]_1^{\text{H}} \mathbf{F}_{n,n} \mathcal{P}_n^{(K)} \mathcal{P}_n^{(K)\text{H}} \mathbf{F}_{n,n}^{\text{H}} [\mathbf{N}(\mathbf{C}_n)]_2$ when calculating $\mathcal{Q}_n$ and the global solution of (13) is,

$$\mathcal{P}_1 = x_{\max}(\mathbf{H}_1 + \mathbf{H}_2) = l_1(\mathcal{P}_2, \dots, \mathcal{P}_N) \quad (14)$$

The ESO algorithm is used to obtain the RX-BFs as secure-form solutions.

C. Combined TX-BF and RX-BF Design for SNR and SINR Maximization

In this case, the multi-objective optimization [17] for fixed method is used. In the previous case, it provides the optimization problem $\mathcal{H}$ but here instead of $\mathcal{H}$, it describes the problem $\mathcal{H}_1$ to perform optimization w.r.t $\mathcal{P}_1$ and $\mathcal{Q}_1$

$$\mathcal{H}_1 : \max_{\mathcal{P}_1 \in \mathbb{C}^{K_t}} \mathcal{P}_1^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1 \mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} \mathcal{P}_1 \quad (15)$$

Equation (15) provides tricky maximization w.r.t to $\mathcal{P}_1$ only. The global minimizer is given as,

$$\mathcal{P}_1 = \gamma [\mathbf{N}(\mathbf{D})]_1 + \delta [\mathbf{N}(\mathbf{D})]_2 \quad (16)$$

From (16) $\mathbf{D} \triangleq [(\mathbf{F}_{2,1}^{\text{H}} \mathcal{Q}_2)^{\text{H}}; \dots; (\mathbf{F}_{N,1}^{\text{H}} \mathcal{Q}_N)^{\text{H}}]$ with $|\gamma| = x_1$ and $|\delta| = x_2$, then x_1 and x_2 are the solutions of following:

$$\begin{aligned} \max_{x_1, x_2} & x_1^2 \mathcal{P}_1 + x_2^2 \mathcal{P}_2 + 2x_1 x_2 \mathcal{P}_2 \\ \text{s.t. } & x_1^2 + x_2^2 \leq 1 \end{aligned} \quad (17)$$

The optimal solution for (17) is given as, $\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = x_{\max} \begin{bmatrix} \mathcal{P}_1 & \mathcal{P}_2 \\ \mathcal{P}_3 & \mathcal{P}_4 \end{bmatrix}$ such that, $\mathcal{P}_1 \triangleq [\mathbf{N}(\mathbf{D})]_1^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1 \mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} [\mathbf{N}(\mathbf{D})]_1$, $\mathcal{P}_2 \triangleq [\mathbf{N}(\mathbf{D})]_2^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1 \mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} [\mathbf{N}(\mathbf{D})]_2$ and $\mathcal{P}_3 \triangleq [\mathbf{N}(\mathbf{D})]_1^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1 \mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} [\mathbf{N}(\mathbf{D})]_2$ are considered as real. The proposed methods are not LS beamforming and thus TX beamformer design with LS beamforming can be obtained by evolutionary algorithms.

From SNR maximization, $\mathcal{Q}_1$ is attained from problem $\mathcal{H}_1$ since $\mathcal{P}_1$ is fixed. By using SINR maximization (problem $\mathcal{H}_2$), $\mathcal{Q}_1$ from each user can be achieved by knowing $\mathcal{P}_1$.

TABLE II
ESO ALGORITHM FOR COMBINED SNR AND SINR MAXIMIZATION

1:	Set $M > 1$; $\mathcal{Q}_i^{(0)}$ for $i=1, \dots, N$
2:	For $k = 0 : M$ do
3:	Compute $\mathcal{P}_i^{(k)} = x_1 [\mathbf{N}(\mathbf{D}_i^{(k)})]_1 + x_2 e^{-j\theta} [\mathbf{N}(\mathbf{D}_i^{(k)})]_2$
4:	$\mathbf{D}_i^{(k)} \triangleq [(\mathbf{F}_{i,j}^{\text{H}} \mathcal{Q}_j^{(k)})^{\text{H}}; \dots; (\mathbf{F}_{i,N}^{\text{H}} \mathcal{Q}_N^{(k)})^{\text{H}}]$
5:	$\theta \triangleq \angle [\mathbf{N}(\mathbf{D}_i^{(k)})]_1^{\text{H}} \mathbf{F}_{i,i}^{\text{H}} \mathcal{Q}_i^{(k)} \mathbf{D}_i^{(k)\text{H}} \mathbf{F}_{i,i} [\mathbf{N}(\mathbf{D}_i^{(k)})]_2$
6:	$\mathcal{Q}_i^{(k+1)} = x_{\max} \left(\left(\sum_{j \neq i}^N \mathbf{F}_{i,j} \mathcal{P}_j^{(k)} \mathcal{P}_j^{(k)\text{H}} \mathbf{F}_{i,j}^{\text{H}} + \frac{\sigma_s^2}{\sigma_i^2} \mathbf{I} \right)^{-1} \mathbf{F}_{i,i} \mathcal{P}_i^{(k)} \mathcal{P}_i^{(k)\text{H}} \mathbf{F}_{i,i}^{\text{H}} \right)$
7:	End for
8:	Stop when criterion met and Return $\mathcal{Q}_i^{(M+1)}$ and $\mathcal{P}_i^{(M)}$

$$\mathcal{H}_2 : \max_{\mathcal{Q}_1 \in \mathbb{C}^{K_r}} \frac{\mathcal{Q}_1^{\text{H}} \mathbf{F}_{1,1} \mathcal{P}_1 \mathcal{P}_1^{\text{H}} \mathbf{F}_{1,1}^{\text{H}} \mathcal{Q}_1}{\mathcal{Q}_1^{\text{H}} \left(\sum_{j \neq 1}^N \mathbf{F}_{1,j} \mathcal{P}_j \mathcal{P}_j^{\text{H}} \mathbf{F}_{1,j}^{\text{H}} + \frac{\sigma_s^2}{\sigma_1^2} \mathbf{I} \right) \mathcal{Q}_1} \quad (18)$$

The unique global solution of problem $\mathcal{H}_2$ w.r.t $\mathcal{Q}_1$,

$$\mathcal{Q}_1 = x_{\max} \left(\left(\sum_{j \neq 1}^N \mathbf{F}_{i,j} \mathcal{P}_j \mathcal{P}_j^H \mathbf{F}_{i,j}^H + \frac{\sigma_n^2}{\sigma_s^2} \mathbf{T} \right)^{-1} \mathbf{F}_{1,1} \mathcal{P}_1 \mathcal{P}_1^H \mathbf{F}_{1,1}^H \right) \quad (19)$$

All the beamformer designs offered here are secure-forms. This is significant for implementation.

IV. SIMULATION RESULTS

In this section, the examination study for MIMO-OFDM [25] based on statistical results are discussed here. For efficient communication, all the users practice QPSK modulation in the valuation of BER performance. The digital communications performance is a complicated feature of link optimization and using single modulation cannot produce high efficiency over a range of average SNRs. However, optimizing with the analogue objective functions, and smearing a fixed communications outline sanctions fair performance in contrast among different optimized beamformers.

It can be revealed that the ESO over N games can be practical to sum-rate maximization. The final outcome is represented as:

$$\mathcal{P}_i^{\text{sum}} = x_{\max} \left(\mathbf{F}_{i,i}^H \left(\sum_{j \neq i}^N \mathbf{F}_{i,j} \mathcal{P}_j^{\text{sum}} (\mathcal{P}_j^{\text{sum}})^H \mathbf{F}_{i,j}^H + \frac{\sigma_n^2}{\sigma_s^2} \mathbf{T} \right)^{-1} \mathbf{F}_{i,i} \right) \quad (20)$$

The above mentioned problem has been solved by gradient based approach in [8]. Thus, the outcomes of gradient based approach and proposed Elongated Successive Optimization. However, the proposed algorithm shows lower bit error performance. The results are stimulated based on QPSK modulation in OFDM channel. From Fig. 2, the BER performance of three proposed beamforming designs are plotted. The combined multi-objective TX-BF and RX-BF approach (case 3) has improved performance than the combined single-objective TX-BF and RX-BF approach (case 2) and lastly the individual approach (case 1).

From Fig. 2, the BER performance of three proposed beamforming designs are plotted. The combined multi-objective TX-BF and RX-BF approach (case 3) has improved performance than the combined single-objective TX-BF and RX-BF approach (case 2) and lastly the individual approach (case 1). From Fig. 2, the case 2 has the BER performance less than 10^{-4} at SNR=10 db. Fig. 3 shows that it also has improved sum-rate performance and lower BER performance. This is measured from comparing the execution times with deriving the TX-BF for LS criteria using an evolutionary algorithm (GA) at a specified average SNR. The sum rate in bits/Hz is calculated by, $\sum_{i=1}^N \log_2(1 + \text{SINR}_i)$. Averaging over 100 realizations, case 3 is five times faster than LS with GA for $N=4$ users. Fig. 4 compares the sumrate maximization by ESO with sumrate maximization by gradient descent method discussed in [8].

TABLE III
SUMMARY OF SETUP PARAMETERS AND THEIR SIZES

Symbol	Name	Size
$\mathbf{R}$	Number of subcarriers	16
$\mathbf{N}$	Number of users	$N, N+1$
$\mathbf{K}_t$	Number of transmitter antenna per user	$N+1$
$\mathbf{K}_r$	Number of receiver antenna per user	$N, N+1$
$\mathbf{L}+1$	Channel length	Scalar
$\mathbf{L}_{cp}$	Cyclic Prefix	Scalar
$\mathbf{M}$	ESO Iterations	16

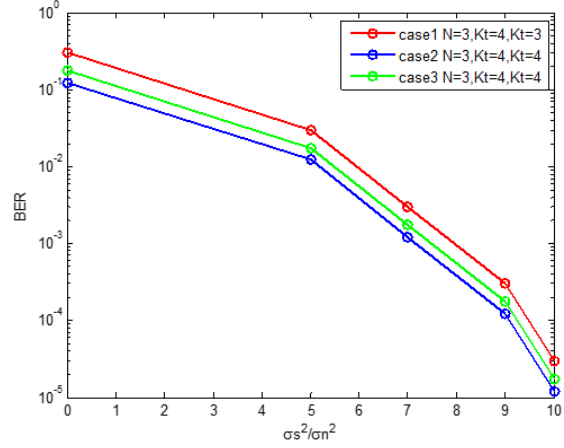


Fig. 2 The BER performance for proposed beamforming designs for $N=3$ and $G(0,1)$ channels

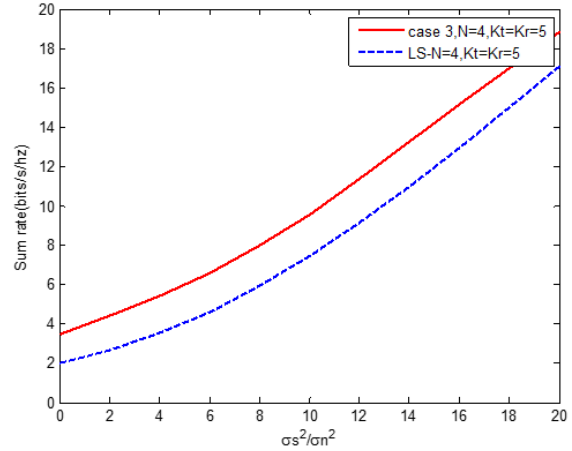


Fig. 3 The sum rate performance of case 3 and LS TX beamforming design for $N=4$ users

From Fig. 4, the performance loss is only 0.8 db. Then the computational complexity of gradient method is given by $O(KN^2M^3)$ where $M = \max(K_r, K_t)$. Though, the computational complexity for proposed ESO is denoted by $O(KNM^3)$. The computational time is five times faster for the special case $M=4$ and $N=3$. The proposed Elongated Successive Optimization shows much lower computational time than the existing beamforming methods.

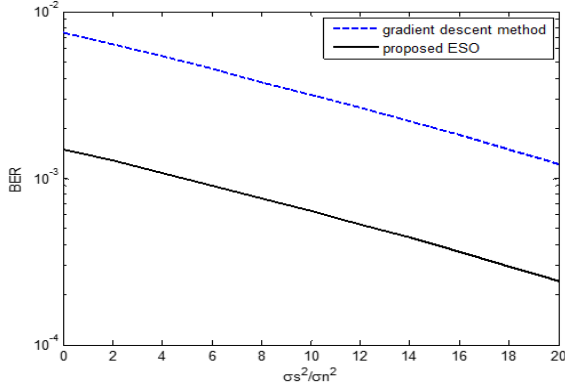


Fig. 4 The BER performance comparison of gradient method and proposed ESO for N=3 and G(0,1) channels

V. CONCLUSION

In this paper, we provide the framework for distinct and combined design of TX and RX beamformers in a MIMO-OFDM multiuser transmission based on beamforming strategies. Thus to enhance the performance and to minimize the bit error performance, this paper presents three beamforming designs for MIMO-OFDM interference channels. The proposed algorithm aimed at combining the TX and RX beamformers for controlled SNR and SINR maximization. This algorithm comprise iterative measures with secure-form steps, allowing the fast solution. The third algorithm- combined controlled SNR and SINR maximization overtakes the least square (LS) beamforming design with lower computational time. The second algorithm provides low BER whereas the first algorithm is the modest in terms of complexity. The simplicity of proposed algorithm comparison illustrates its better performance than existing method. In a subsequent work, this beamforming designs along with the proposed algorithm will be used to elicit multipath diversity using linear constellation precoder in order to improve the error performance in multiuser MIMO-OFDM interference channels.

APPENDIX

A. Elongated Successive Optimization (ESO)

This ESO algorithm is an iterative procedure for maximizing the function successively by combining over all variables limited over individual subsets. It is mainly used for multi-objective optimization problem. The sum of objective functions are taken as:

$$\min_{y \in \Omega_i} I(y) = I_1(y_1, \dots, y_N) + \dots + y_N(y_1, \dots, y_N) \quad (21)$$

The main sign of ESO is to switch this difficult combine optimization problem (21) of $I_1(y)$ over the sub-problems:

$$\min_{x_i \in \Omega_i} I_i(y_1, \dots, y_{i-1}, y_i, y_{i+1}, \dots, y_N) \quad (22)$$

where $(y_1, \dots, y_{i-1}, y_{i+1}, \dots, y_N)$ are fixed the unique global solution minimizer is given as,

$$y_i = l_i(y_1, \dots, y_{i-1}, y_{i+1}, \dots, y_N) \quad i = 1, \dots, N \quad (23)$$

For $y_1, \dots, y_{N-1}$ outline:

$$y_{N-1} = l_{N-1}(y_1, \dots, y_{N-2}, l_N(y_1, \dots, y_{N-1})) \\ \triangleq g_{N-1}(y_1, \dots, y_{N-1}) \quad (24)$$

Such that $y \triangleq [y_1, \dots, y_{N-1}]^T$ and $g \triangleq [g_1, \dots, g_{N-1}]^T$. If for some ϵ ,

$$\|l_i\| \leq \epsilon \text{ for } \|\text{col}\{y_1, \dots, y_{i-1}, y_{i+1}, \dots, y_N\}\| \leq \epsilon$$

Then from Brouwer's theorem such that,

$$I_N(y_1^*, y_2^*, \dots, y_{N-1}^*, y_N^*) \leq I_2(y_1^*, y_2^*, \dots, y_{N-1}^*, y_N) \quad (25)$$

Thus, y^* obtained by ESO is said to be a Nash Equilibrium (NE) for N games. One of the simplest approximation is,

$$y_i^{(n+1)} = l_i(y_1^{(n+1)}, \dots, y_{i-1}^{(n+1)}, y_{i+1}^{(n)}, \dots, y_N^{(n)}) \quad (26)$$

Linking the y^* to the stationary solution of original problem (21) is an exposed problem. To produce multi-objective optimization the elongated successive optimization is effectively used by joining the TX and RX beamformers.

REFERENCES

- [1] S. Peters and R. Heath, "Cooperative algorithms for MIMO interference channels," IEEE Trans. Veh. Technol., vol. 60, no. 1, pp. 206-218, Jan 2011.
- [2] H. Bolcskei, D. Gesbert, and A. J. Paulraj, "On the capacity of OFDM based spatial multiplexing systems," IEEE Trans. Commun., vol. 50, no. 2, pp. 225-234, Feb. 2002.
- [3] D. Gesbert, M. Shafi, D.S. Shiu, P. J. Smith, and A. Naguib, "From theory to practice: An Overview of MIMO space-time coded wireless systems," IEEE J. Sel. Areas Commun., vol. 21, no. 3, pp. 281-302, Apr. 2003.
- [4] A. Goldsmith, S. A. Jafar, N. Jindal, and S. Vishwanath, "Capacity limits of MIMO channels," IEEE J. Sel. Areas Commun., vol. 21, no. 5, pp. 684-702, Jun. 2003.
- [5] M. Schubert and H. Boche, "Solution of multiuser downlink beamforming problem with individual SINR constraints," IEEE Trans. Veh. Technol., vol. 53, no. 1, pp. 18-28, Jan. 2004.
- [6] A. Bourdoux and N. Khaled, "Joint TX-RX optimization for MIMO-SDMA based on a null-space constraint," in Proc. IEEE VTC Fall, 2002, vol. 1, pp. 171-174.
- [7] M. Codreanu, A. Tolli, M. Juntti, and M. Latva-aho, "Joint design of TX-RX beamformers in MIMO downlink channel channel," IEEE Trans. Signal Process., vol. 55, no. 9, pp. 4639-4655, Sep. 2007.
- [8] H. Sung, S. H. Park, K.-J. Lee, and I. Lee, "Linear precoder designs for K-user interference channels," IEEE Trans. Wireless Commun., Vol. 9, no. 1, pp. 291-301, Jan 2010.
- [9] T. Tang and R. W. Heath, "Space-time interference cancellation in MIMO-OFDM systems," IEEE Trans. Veh. Technol., vol. 54, no. 5, pp. 1802-1816, Sep. 2005.
- [10] H. Shen, B. Li, M. Tao, and X. Wang, "MSE-based transceiver designs for the MIMO interference channel," IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3480-3489, Nov. 2010.
- [11] M. Schubert and H. Boche, "Iterative multiuser uplink and downlink beamforming under SINR constraints," IEEE Trans. Signal Process., vol. 53, no. 7, pp. 2324-2334, Jul. 2005.
- [12] O. El Ayach, S. Peters, and R. Heath, "The feasibility of interference alignment over measured MIMO-OFDM channels," IEEE Trans. Veh. Technol., vol. 59, no. 9, pp. 4309-4321, Nov. 2010.

- [13] A. Pollok, W. Cowley, and N. Letzepis, "Symbol-wise beamforming for MIMO-OFDM transceivers in the presence of co-channel interference and spatial correlation," *IEEE Trans. Wireless Commun.*, vol. 8, no. 12, pp. 5755-5760, Dec. 2009.
- [14] E. Perahia and R. Stacey, *Next Generation Wireless LANs*. Cambridge, U.K.: Cambridge Univ. Press, 2008. (Online). Available: <http://dx.doi.org/10.1017/CB09780511541032>
- [15] M. A. Toutounchian and R. G. Vaughan, "Multi-objective optimization for multiuser MIMO interference channels," *IEEE Trans. Commun.*, to be published.
- [16] Y.-F. Liu, Y.-H. Dai, and Z.-Q. Luo, "Max-min fairness linear transceiver design for a multi-user MIMO interference channel," in *Proc. IEEE ICC*, Jun. 2011, pp. 1-5.
- [17] M. Toutounchian and R. Vaughan, "SINR-based transceiver design in the K-user interference channel using multi-objective optimization," in *Proc. IEEE 78th VTC Fall*, Sep. 2013, pp. 1-5.
- [18] L. Schumacher, K. Pederson, and P. Mogensen, "From antenna spacings to theoretical capacities-Guidelines for stimulating MIMO systems," in *Proc. IEEE 13th Int. Symp. Pers., Indoor Mobile Radio Commun.*, Sep. 2002, vol. 2, pp. 587-592.
- [19] S. W. Choi, S. Jafar, and S.-Y. Chung, "On the beamforming designs for efficient interference alignment," *IEEE Commun. Lett.*, vol. 13, no. 11, pp. 847-849, Nov. 2009.
- [20] A. Van Zelst and T. Schenk, "Implementation of a MIMO-OFDM based wireless LAN system," *IEEE Trans. Signal Process.*, vol. 52, no. 2, pp. 483-494, Feb 2004.
- [21] R. Blum, "MIMO capacity with interference," *IEEE J. Sel. Areas Commun.*, vol. 21, no. 5, pp. 793-801, Jun. 2003.
- [22] F. Kaltenberger, M. Kountouris, D. Gesbert, and R. Knoop, "On the tradeoff between feedback and capacity in measured MU-MIMO channels," *IEEE Trans. Wireless Commun.*, vol. 8, no. 9, pp. 4866-4875, Sep. 2009.
- [23] R. Zhang and Y.-C. Liang, "Exploiting multi-antennas for opportunistic sharing in cognitive radio networks," *Selected Topics in Signal Processing*, *IEEE Journal of*, vol. 2, no. 1, pp. 88-102, Feb 2008.
- [24] M. Maddah-Ali, A. Motahari, and A. Khandani, "Communication over MIMO X channels: interference alignment, decomposition, and performance analysis," *Information Theory, IEEE Transactions on*, vol. 54, no. 8, pp. 3457-3470, Aug 2008.
- [25] G. Zheng, K.-K. Wong, and T.-S. Ng, "Throughput maximization in linear multiuser MIMO-OFDM downlink systems," *IEEE Trans. Veh. Technol.*, vol. 57, no. 3, pp. 1993-1998, May 2008.



processing.

K.G. Jothi Shalini has received her B.E Degree in Electronics and Communication Engineering in 2014 from National Engineering College Kovilpatti, Thoothukudi(India).She is currently pursuing M.E in Electronics and Communication Engineering at Francis Xavier Engineering College Tirunelveli (India).Her research interests include Communication Systems, Digital signal Processing, Embedded Systems and Image



Ruba Soundar received the A.M.I.E., degree in Computer Science and Engineering from the Institution of Engineers (India) in 2000. He received the M.E., and Ph.D., degrees in Computer Science and Engineering from Anna University, Chennai in the year 2004 and 2010 respectively. Currently he is a Professor in Computer Science and Engineering Department of P.S.R.

Engineering College, Sivakasi, Tamil Nadu, India. He has authored / co-authored over 75 research articles in various Journals and Conferences in the areas of Image Processing, Wireless and Wired Networking



R. Vedha Priya Vadhana B.E degree Biomedical Instrumentation Engineering from Avinashilingam Deemed University in 2005. She received the M.Tech degree in Computer and Information Technology from Manonmaniam Sundaranar University, Tirunelveli in the year 2009 and Currently pursuing Ph.D in Information and Communication in Anna University, Chennai. At Present she is working as Assistant Professor and Head of the Department in Electronics and Communication

Engineering Department of Francis Xavier Engineering College, Tirunelveli Tamil Nadu, India. She has authored / co-authored over 15 research articles in various Journals and Conferences in the areas of Image and Video Processing, Embedded System and Bio Medical Instrumentation.