Binary Weightbook Design for MIMO OFDM System Using Quantized Feedback

Sadguna Kumari V1, AM Prasad2

1UCEK, JNTUK, Kakinada, A.P, India
2Professor & HOD, Department of Electronics and Communication Engineering, UCEK, JNTUK, Kakinada, A.P, India

Abstract: A particularly promising candidate for next-generation fixed and mobile wireless systems is the combination of MIMO technology with Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a subset of frequency division multiplexing in which a single channel utilizes multiple sub-carriers on adjacent frequencies. MIMO wireless systems are of interest due to their ability to provide substantial gains in capacity and quality. Transmit Beam forming and Receive combining are simple methods for exploiting significant diversity that is available in MIMO wireless systems. Orthogonal Frequency Division Multiplexing (OFDM) effectively deals with detrimental effects caused due to frequency selective fading, which is the major challenging issue in wireless communications. Optimal performance of MIMO-OFDM systems require complete knowledge about the channel and this is hard to realize hence a feedback path is to be established from transmitter to the receiver. The optimum Binary Weightbook is designed which uses quantized feedback from receiver to the transmitter. The performance of Binary Weightbook is almost same as the Grassmannian Weightbook which uses unquantized feedback.

Keywords: Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Transmitter diversity, Quantized feedback, Binary Weightbook, Grassmannian Weightbook.

1. Introduction

OFDM is a Frequency Division Multiplexing (FDM) scheme used as a digital Multi-carrier modulation method. A large number of closely spaced orthogonal sub carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

In OFDM the high speed data stream is divided into $N_c$ narrowband data streams, $N_c$ corresponding to the subcarriers or sub channels. The symbol duration is made longer by adding a cyclic prefix to each symbol. As long as the cyclic prefix is longer than the channel delay spread, OFDM offers Inter-Symbol Interference (ISI) free transmission.

Multiple Input Multiple Output (MIMO)-Orthogonal Frequency Division Multiplexing (OFDM) has attracted researchers interest as they improve the parameters of the wireless communication like transmission rate, transmission reliability and transmission range simultaneously.

Closed loop systems make use of feedback concept to improve the performance of wireless communication[2]. Closed loop Transmit beamforming is of prior importance as it enhances the quality of the wireless link thereby improving the throughput of the system. Achieving maximum diversity in MIMO-OFDM systems is by making use of beamforming at the transmitter and combing at the receiver side[12]-[15] which is the simplest way.

Binary weightbook[1] is a form of finite alphabet weightbooks like Grassmannian weightbook. Binary weightbook design for MIMO-OFDM systems uses quantized feedback. This reduces the storage requirements of the weightbook.[3],[14]

2. System Model

A block schematic of the MIMO OFDM [13],[14] using Binary Weightbook with $N_t$ transmitting and $N_r$ receiving antennas is as shown in the Fig 2.1. Here the symbol’s is pre-encoded using the beamforming weight vector $w=[w_1, w_2, ..., w_w]$ from a Binary Weightbook W. Here $(.)^T$ denotes the transpose and $w = 1$ or -1.

The transmitted symbols are received by the $rN$ receiving antennas followed by the FFT based demodulation.

The Trellis-Coded symbols[8] are applied to the IFFT- based OFDM modulators, followed by their transmission over $N_t$ transmitting antennas after multiplying with optimum weight vector. Here the weightbook consists of $2^F$ beamforming vectors, where $F$ is the number of feedback bits. The receiver sends the feedback to the transmitter by selecting the beamforming vector $w$ from the weightbook W.

The transmitted symbols are received by the $N_r$ receiving antennas followed by the FFT based demodulation.
Maximum Ratio combining (MRC) [16] detection scheme is employed at the receiver side. The output signal at the receiver is given as

\[ r = \sqrt{\frac{E_s}{N_t}} z^H H w s + z^H n \]

Here \( E_s \) is the energy of the signal and \( N_t \) is the number of transmitting antennas. \( H \) is the \( N_t \times N_r \) channel matrix. MRC combining vector at the receiver \( Z \) is equal to \( H w \).

3. Weight Book Design

3.1 Grassmannian Weightbook

Grassmannian line packing: Grassmannian line packing is the problem of optimally packing one-dimensional subspaces. It is similar to the problem of spherical code design with one important difference: spherical codes are points on the unit sphere while Grassmannian line packings are lines passing through the origin in a vector space. Grassmannian line packing forms the basis for our quantized beamforming codebook design.

Grassmannian Beamforming Criterion: Design the set of codebook vectors \( \{w_i\}_{i=1}^N \) such that the corresponding codebook matrix \( W \) maximizes [10]

\[ \delta(W) = \min_{1 \leq k < l \leq N} \sqrt{1 - \left| w_k w_l^H \right|^2} \]

This criterion captures the essential point about quantized beamforming codebook design for Rayleigh-fading MIMO wireless systems. Grassmannian line packings are the key to codebook construction. Thus, beamforming codebooks can be designed without regard to the number of receiver antennas by thinking of the codebook as an optimal packing of lines instead of a set of points on the complex unit sphere. One benefit of making the connection between codebook construction and Grassmannian line packing is that it provides an approach for finding good codebooks, namely, leveraging work that has already been done on finding optimal line packings.

The codebook matrix \( W \) must satisfy

\[ W = \arg \max_{X \in I} \delta(X) \]

where \( I_{M,N} \) is given by the set of matrices for codebook.

3.2 Binary weightbook design:

Defining Binary Phase Shift Keying (BPSK) mapping, BPSK(0) = 1, BPSK(1) = −1. Then, define inverse BPSK mapping, \( BPSK^{-1}(\cdot) \), as \( BPSK^{-1}(0) = 0 \) and \( BPSK^{-1}(1) = 1 \).

Binary Weightbook design is to maximize the minimum distance of the unified code. The Binary Weightbook is designed in such a way that the minimum distance between the corresponding code must be less than or equal to \( \frac{N_t}{2} \). For a Binary Weightbook \( W \) number of beamforming vectors is equal to \( 2^F \), where \( F \) is the number of feedback bits. Length of the beamforming vector is equal to number of transmitting antennas. Given \( N_t \) and \( F \), we will design a code \( C \) of which the column vectors are the \( 2^r \) codewords. Then, the corresponding Binary Weightbook can be found using BPSK mapping.

Case(i) • Binary Weightbook when number of transmitting antennas \( N_t \) is equal to 3 and number feedback bits \( F \) is equal to 1

\[ W = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \end{bmatrix} \]

Here \( F=1 \), number of beamforming vectors is equal to \( 2^{1} = 2 \). The minimum Hamming distance for the unified code is one. Since this code achieves the bound, it is optimum.

Case(ii) • Binary Weightbook when number of transmitting antennas \( N_t \) is equal to 3 and number feedback bits \( F \) is equal to 2

\[ W = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \]

Here \( F=2 \), number of beamforming vectors is equal to \( 2^{2} = 4 \).

Selection of Beamforming weight vector : Beamforming weight vector \( w \) from the Weightbook \( W \) in Binary Weightbook design is found by

\[ w = \arg \max_{w \in \mathbb{W}} \left\| H w \right\|^2 \]

\[ = \arg \max_{w \in \mathbb{W}} \sum_{i=1}^{M} \sum_{j=1}^{M} h_{i,j} w_i w_j \]

here \( ||.|| \) indicates the norm and \( H \) indicates the channel matrix. \( h_{i,j} \) indicates the channel for \( i \)th receiving and \( j \)th transmitting antenna.

4. Simulation Results

Comparison between performance of MRC (Maximum Ratio Combining) and Binary Weightbook for MIMO OFDM Systems.
MIMO OFDM systems with MRC and Binary Weightbook techniques are designed. Fig. 4.1 shows Binary Weightbook gives better performance compared with MRC. Modulation scheme employed here is BPSK (Binary phase shift keying).

Comparison between performance of Binary Weightbook and Grassmannian Weightbook for MIMO OFDM Systems:

MIMO OFDM systems with Binary Weightbook and Grassmannian Weightbook techniques are designed. Fig. 4.2 shows Grassmannian Weightbook gives better performance compared with Binary Weightbook. Modulation scheme employed here is BPSK (Binary Phase Shift Keying).

Comparison between performance of MIMO and MIMO-OFDM systems:

MIMO OFDM systems with Binary Weightbook and Grassmannian Weightbook are designed for MIMO and MIMO-OFDM systems. Fig. 4.3 shows MIMO OFDM system gives better performance compared with MIMO system. Modulation scheme employed here is BPSK (Binary phase shift keying).

Comparison between performance of Binary Weightbook when receiver Antennas equal to 1 and 2:

Binary Weightbook with 1 and 2 receiver antennas is designed. Fig. 4.4 shows as the receiver antennas increases the performance of the system increases. Modulation scheme employed here is BPSK (Binary Phase Shift Keying).
Comparison between performance of Binary Weightbook when $M_t=2, M_r=2$ and $M_t=4, M_r=4$

![Comparison diagram]

**Figure 4.5:** Performance comparison of Binary Weightbook when $M_t=2, M_r=2$ and $M_t=4, M_r=4$.

Binary Weightbook for $M_t=2, M_r=2$ and $M_t=4, M_r=4$ is designed. Fig 4.5 shows as the $M_t$ and $M_r$ increases the performance of the system increases. Modulation scheme employed here is BPSK (Binary Phase Shift Keying).

5. Conclusion

The performance of Grassmannian Weightbook is almost similar to that of Binary weightbook design. But the computational complexity for finding the optimum beamforming weight vector and the storage requirement for the Binary Weightbook can be reduced compared with that of Grassmannian Weightbook.

References


[2] Coding for MIMO Communication Systems Tolga M. Duman Arizona State University, USA


[11] MIMO-OFDM WIRELESS COMMUNICATIONS WITH MATLAB Yong Soo Cho Chung-Ang University, Republic of Korea, Jaekwon Kim Yonsei University, Republic of Korea Won Young Yang Chung-Ang University, Republic of Korea Chung G. Kang Korea University, Republic of Korea


Author Profile

Sadguna Kumari V is M.TECH Student, University College of Engineering, JNTUK, Kakinada, A.P, India.

AM Prasad is Professor & Head of the Department, Department of Electronics and communication Engg., University College of Engineering, JNTUK, Kakinada, A.P, India.