A Study on Complexity Reduction for Space-Time Block Codes Decoder in MIMO OFDM systems

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ABSTRACT

In this work, we first present our study on the decoding schemes for space-time block code as well as our comments on their complexity. Then, we propose a new modified complex sphere decoding scheme, which has lower computational load than that of conventional complex sphere decoders. In the proposed scheme, the boundary for searching is defined by the intersection of an approximate polygon of searching circle and disk of lattice constellation. Therefore, the proposed scheme can reduce the searching boundary and it can avoid missing searching points as well. The performance of the proposed scheme, which is verified by computer simulations, consolidates our scheme.

Keywords

Space Time Code, Sphere Decoding, Multiple-Input Multiple-Output (MIMO) system, Orthogonal Frequency Division Multiplexing (OFDM) system

I. Introduction

Recently, the demand of high-speed wireless data service has motivated a significant effort in the communication research community. The limitation in spectrum challenges the researcher to design modern wireless system, which must not only be more reliable and spectral efficient than ever but also facilitate the high-speed data transmission. Multiple-Input Multiple-Output (MIMO) system [1] has been proposed to meet the aforementioned demand. By exploiting multiple antennas at both transmitter and receiver, MIMO system can offer enormous advantages such as diversity gain and multiplexing gain.

In addition, Orthogonal Frequency Division Multiplexing (OFDM) signaling [2], has been considered a leading technique for the next generation high-speed wireless communication systems. In OFDM technique, the transmitted signal has relatively long symbol duration, thus it has narrow bandwidth. Consequently, the system gains a noticeable advantage of robustness in selective-fading environment [3]-[4] with a good frequency usage efficiency. It is also noticeable that the OFDM modulation and demodulation can be implemented in discrete-domain by using a Discrete Fourier Transform (DFT), which can be efficiently implemented by using the Fast Fourier Transform (FFT). Therefore, the signal can be easily transmitted and received without increasing of transmitter and receiver complexities.

In the literature, most researches have exploited either diversity gain or multiplexing gain. Unfortunately, there exists tradeoff between the two gains [5]. Thus, the judicious signal processing approaches have to be applied to solve that trade-off. Space-time coding [6]-[9], [16] is a promising technique for signal processing in MIMO system. Space-Time Coding can provide diversity gain as well as coding gain by performing a joint coding in both spatial and temporal domain. Thus, it can significantly improve the system performance and facilitate very high data rate. In [6], the authors proposed a simple space-time block code (STBC) for two transmit antenna. The scheme is known that its receiver is simple while it can achieve the performance as

Maximum likelihood receiver does. However, it does not provide coding gain but diversity gain. In contrast to STBC, space-time trellis code (STTC) can achieve both a full diversity order and a coding gain. The outperform of STTC is traded at the cost of extremely high complexity in receiver.

In the MIMO system with space time code, the high data rates are obtained by employing many transmit antennas and high order signal constellation such as M-PSK, M-QAM. Thus it challenges us in optimal receiver design. The optimum receiver is based on brute-force maximum likelihood (ML) detection. Unfortunately, the complexity of this approach exponentially proportion to the number of possible constellation points. Thus, it is infeasible to apply ML detection to practical system. A number of suboptimal solutions with low complexity have been proposed. However, all of them trade the low complexity with loss of performance. Most notable among complexity reduction algorithm is sphere decoding (SD)[10]-[15]. The SD algorithm tries to solve the problem of finding the closest lattice point from the ML problem. However, the complexity of SD is reduced by limiting the search region inside a hyper-sphere with certain radius.

In this work, we present our research on the complexity reduction of STBC decoder and a new modified sphere decoding. With the modified searching boundary, the proposed SD scheme can achieve advantage in term of complexity reduction in low SNR regime. The system model for consideration is presented in Section II. The related works on decoding scheme for STBC are presented in Section III. The motivation of our work is given in Section IV. Section V shows the computer simulation result to verify our work. Finally, the conclusion of our work is given in Section VI.

II. System model

Let us consider the MIMO-OFDM system that has M transmit antennas and N receiver antennas. The user data is demultiplexed into M sequences. Each sequence is mapped by the same constellation of high order signal constellation such as M-PSK or M-QAM. After that, the mapped symbol signals are modulated by inverted Fast Fourier Transform (IFFT) to produce the transmit signal.

Let $s=[s_1, s_2, \cdots, s_M]^T$ denoted the vector of transmit symbols. The received signal vector can be written as:

$$y = Hs + n \tag{1}$$

In the equation (1), H is a complex channel matrix. It is assumed to be perfectly known at the receiver. And n is a vector of independent zero-mean Gaussian noise.

At the receiver, the receiver demodulates the received signal with FFT to obtain the signal as follows:

$$\hat{y} = FHs + Fn \tag{2}$$

F denote the FFT transform matrix. Thus, the optimal ML detection problem of the system becomes:

$$\hat{d} = \underset{d \in D}{\arg\min} \| \hat{y} - Gd \|^2 \tag{3}$$

Where $G = FHF^{-1}$, d is the constellation point of transmit signal.

III. Decoding schemes for Space Time Block Code

The practical solution for (3) can be one of some approximate approaches, heuristics or combination of thereof.

A. The approximation approaches

The approximations can be named as:

Zero-Forcing: The first one can be known as Zero-Forcing approach. It solves the unconstrained least-squares problem to obtain:

$$\hat{d} = G^{+}\hat{y} \tag{4}$$

In (4), G^{+} is the pseudo-inverse of G.

MMSE: The second is minimum mean square error (MMSE) solution, which results in:

$$\hat{d}_{mmse} = (G^H G + SNR I)^{-1} G^H \hat{y} \tag{5}$$

Nulling and canceling: In this approach, we consider only one of the entries, for example, the first entry x_1. Then x_1 is assumed to be known and its contribution is cancelled out to obtain the reduced order of problem to M-1 unknowns.

Nulling and canceling with optimal ordering: The above nulling and canceling approach can suffer from error propagation, i.e. the correctness of estimation of $x_1$critically affects to the correctness of estimation of remaining unknowns. V-BLAST [16] is known as a solution for this problem.

All of these approximation approaches can avoid the problem that the complexity is exponentially proportion to order of modulation. However, their performances are much degraded.

B. Heuristic search approach

The heuristic search to solve the problem in (3) seems infeasible in practical system when the high data rates are obtained by exploiting high order of signal constellation point modulation scheme.

C. Sphere decoding approach

The basic premise in sphere decoding is rather simple. Instead of heuristic searching, we only attempt to search over lattice points lie in a certain hyper-sphere of radius r around the given received vector. Thereby, the computation load required for SD is significantly reduced. It is widely known that the complexity order of SD is polynomial function. However, the crucial issues in SD are the choice of initial radius for searching and the approach to translate whether a point is inside or outside the hyper-sphere. The small initial radius may result in failure of searching, then the search have to re-start with a bigger radius. On the other hand, the large initial radius requires much more searches. Thus, it is not optimal in term of computation load.

The SD problem can be stated as: With the lattice points Gd, we consider the points lie inside the hyper-sphere of radius r:

$$\| \hat{y} - Gd \|^2 \leq r^2 \tag{6}$$

By using the QR decomposition of the matrix G, i.e. G =[Q Q'][R 0]^T, where R is upper triangular with diagonal element real and positive, Q is unitary matrix, the equation (6) can be rewritten as:

$$\| Q^T \hat{y} - Rd \|^2 \leq r^2 \tag{7}$$

$$\| y' - Rd \|^2 \leq r_1^2 \tag{8}$$

In the equation (8), $y = Q^T \hat{y}$ and $r_1 = \sqrt{r^2 - |Q'^T \hat{y}|^2}$. With the obtained equation (8), the limit region for searching to point of the constellation is defined.

IV. Proposed modified complex sphere decoding

The solution of general bound is presented in [11], where the intersection of a disk of lattice and a circle searching boundary is found by solving the inverse function of cosine and tangent. Then the $\cos^{-1}()$ and $\tan^{-1}()$ calculations are required several times per detection for high order constellation modulation scheme.

The simplified boundary is presented in [13], where the circle searching boundary is simplified into a square, which is out-bound of the current circle searching boundary. The finding point for problem (8) can be achieved with the simple comparison of real and imaginary of the considered point to the bound of square. Unfortunately, under the low SNR regime, the lattice distribution is shrunk (cf. Figure 1 and 2). Thus, [13] has to test much more points than the original method [11] does. Consequently, it suffers the heavier computation load in this SNR regime.

Therefore, we present a new modified SD whose boundary is a octagon, which is out-bound of the current circle searching boundary. It is clear that the intersection computation is simpler than [11]. Moreover, in low SNR regime, the number of points required to test is much less than that of [13]. Consequently, the proposed scheme can outperform that of [13] in term of complexity in low SNR regime.

V. Computer simulation results

In our simulations, the data block length is set equal to 256 symbol durations. The channel matrix H is generated randomly and assumed

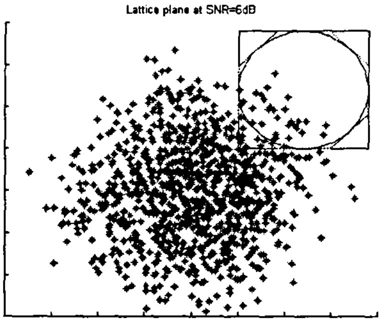

Figure 1: Lattice point distribution in low SNR regime

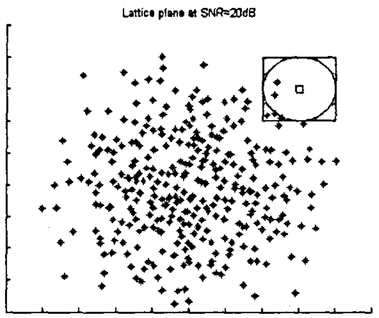

Figure 2: Lattice point distribution in high SNR regime

to be constant in one block transmission and independently changed from one block to the other. The size of FFT is equal to 256. The number of transmit antennas is equal to number of receive antenna and is set to 3.

The Bit Error Rate (BER) performance comparison is presented in Figure 3. As can be seen, at low SNR regime, BER performance of the proposed SD is nearly the same as that of optimal ML detection and lower than that of [13]. However, when SNR increases, the difference of the BER performance of the two - the proposed SD and [13] - decreases. In the high SNR regime, SNR is greater than 25dB as from the Figure 3, BER performance of the proposed SD becomes worse than that of [13].

Figure 4 presented the relative decoding complexity as function of SNR. In our estimation, the complexities are counted by the number of float point calculations. As expected, the proposed SD scheme provides

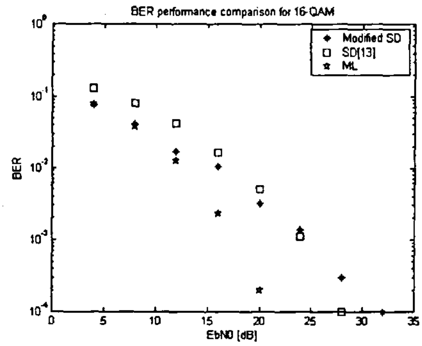

Figure 3: BER Performance

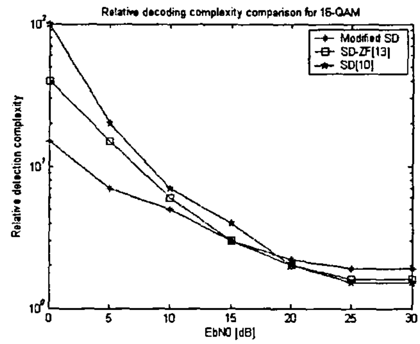

Figure 4: Comparison of relative decoding complexity as SNR varies

gain in term of lower computation load in comparison with the original SD [10] and [13] when SNR is lower than 15 dB. The lower computation load can be explained as follows. In the this SNR regime, due to the shrink of lattice distribution, complexity resulted from extra testing point in [13] is much more that that resulted from the proposed scheme.

VI. Conclusion

In the work, we have presented a new modified sphere decoding, whose boundary is simplified into octagon, which is an outer-bound of original searching boundary. With the new boundary, the proposed scheme can achieve gain in both BER performance and computation load in low SNR region. Therefore, it is highly applicable for the modern systems that operate in low SNR condition.

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