Low Complexity Receiver Concepts for Generalized Spatial Modulation (GSM) MIMO Applications

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***Abstract*—MIMO (Multiple Input Multiple Output) systems have been instrumental for high data throughput in the present day communication systems. The initial concept of diversity to overcome deep fades was soon replaced by Spatial Multiplexing (SMX). Although SMX has high spectral efficiency, the power efficiency remains poor as the system needs to operate many RF channels. This was overcome by Generalized Spatial Modulation (GSM) which maintains a balance between both spectral and energy efficiency. However, this was at the cost of detection complexity as the optimal ML detection would require an exhaustive search. In this paper, we analyze various low complexity sub-optimal receiver schemes as applicable in GSM-MIMO systems.**

***Index Terms*—Energy efficiency, Generalized Spatial Modulation (GSM), Ordered Block Minimum Mean Squared Error (OB-MMSE).**

I. Introduction

EVOLUTION of technology in communication system from a single transmit and receive antenna (Single-Input Single-Output (SISO)) to Multiple-Input Multiple-Output (MIMO) was driven by the need of high data rate applications [1]. The problems of SISO system, primarily the deep fade conditions, were overcome by diversity techniques as the first MIMO application. Data streams of different symbols were simultaneously transmitted by multiplexing over multiple antennas in the spatial dimension, also named as Spatial Multiplexing (SMX). One such application is Vertical-Bell Laboratories Layered Space-Time (V-BLAST) which demonstrated high spectral efficiency but was inefficient in power as many RF links were used [2]. Also the problem of inter channel interference (ICI) was prominent as closely spaced antennas transmitted different symbols. However, VBLAST uses a non-linear receiver based on successive interference cancellation (SIC) which also helped to increase the gain of the system and maintain high spectral efficiency.

To increase the gain of the system MIMO was combined with Space-Time Block Coding (STBC) [3]. STBC transmits multiple copies of the information bits and then combines the data collected at the receiver side so as to give an optimal data that was transmitted. A 2X2 MIMO system gives full rate diversity. STBC had the advantage of its pre-coding technique and simpler architecture.

The problem of achieving a better power efficiency was realised by reducing the number of RF links at the transmitter end. Data was transmitted through only one antenna at a time, so that at any instant only one antenna was active out of all the available transmitting antennas. This concept was called Spatial Modulation (SM) which resulted in improved energy efficiency as well as reduced the ICI [4]. In SM a block of information bits is mapped into two parts- a symbol from a chosen constellation diagram and a unique transmit antenna number that was chosen from a set of transmit antennas. These two units combined together increase the overall spectral efficiency by the base-two logarithm of the number of transmit antenna. It has the advantage of high throughput value with low total transmission power as only one RF chain was active at any time instant. Although this reduced the system complexity to a great extent but spectral efficiency and error performance was not comparable to VBLAST. To improve upon the error performance the antenna index of the selected antenna was transmitted instead of the modulated symbols. This technique can be categorised as a special case of SM and was named Space–Shift Keying (SSK) [5].

To further improve the spectral efficiency maintaining a comparatively simple architecture, a combination of transmitting antennas were chosen out of a group of antennas. This being an extension of SM was called as Generalized SM (GSM)[6,7]. On similar lines of SSK, only the antenna indices were transmitted in Generalized SSK (GSSK) [8].

In all these above developments, the number of transmitting antennas was systematically adjusted with a view to obtain a better power efficient system maintaining a good spectral efficiency. However, the received diversity was not compromised as a higher receive diversity improves the channel capacity.

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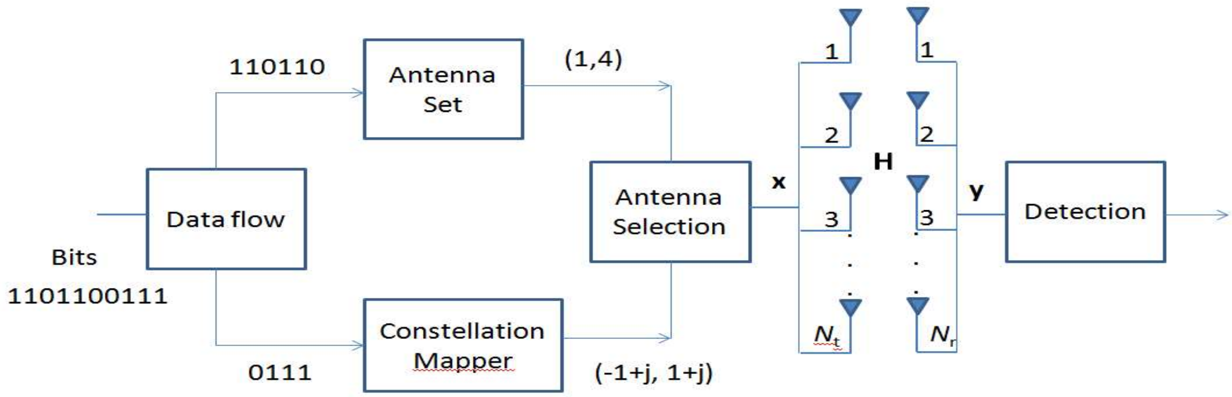

Fig. 1. GSM-MIMO block diagram

Although for a downlink, the user device (mobile handset) demands lesser number of receive antenna for space constraints, yet a much simplified receiver would still have more than two antennas. Moreover, for GSM systems the information is transmitted in two dimensions- space and constellation. This further adds to the complexity of the receiver. In such a situation the optimal ML detection scheme becomes difficult to be implemented. Thus alternative receiver schemes were thought of.

In GSM and its different variants, i.e. SM, SSK and GSSK, sub-optimal detection criteria were proposed, keeping the low computational complexity detection scheme in mind. In [9] and [10], an ordered block minimum mean squared error (OBMMSE) was proposed in which an ordering algorithm was presented to sort the transmit antenna combinations and thereafter the signal vector was detected. In [11] the detection scheme was split in two stages, one for the antenna index and the other for the symbol vector. The authors have proposed Gaussian approximation and QR projection methods for the antenna index detection. A detection algorithm based on enhanced Bayesian compressive sensing is proposed in [12].

In this paper, we compare various types of detection methods and make a performance analysis of these methods proposed in literature. In section II the system model for GSM scheme is discussed as well as different detection methods used to estimate the transmitted information bits at the receiver end. Section III analyses the simulation result and we conclude in Section IV.

II. Detection Methods

A generalized system block diagram of a baseband GSM-MIMO is shown in Fig.1. The incoming information bit sequence is de-multiplexed into two streams, one part to index the antenna subset selection and the other for mapping onto a constellation corresponding to any modulation technique like Binary Phase Shift Keying (BPSK), Quadrature-Phase Shift Keying (QPSK) etc. The modulated signal is thereafter transmitted through the selected group of antennas from among the total number of transmitting antennas.

Let us consider that the number of transmitting antennas is N_t and the number of receiving antennas be N_r. The number of active antenna chosen to transmit the data at any instant of time is N_p. Therefore the available number of combinations to select N_p antennas out of N_t will be given by $C_{N_p}^{N_t}$, where C is the symbol used for combination.

But the combination used will be in the power of two so, the permitted combination will be $N = 2^{\lfloor \log_2 C_{N_p}^{N_t} \rfloor}$.

The information bits through first part of the system model is given as $l_1 = \lfloor \log_2 C_{N_p}^{N_t} \rfloor$ while the second part is $l_2 = N_p \log_2 M$, where M is the set of constellation points Hence the transmitted part will be addition of both the parts $L = l_1 + l_2 = \lfloor \log_2 C_{N_p}^{N_t} \rfloor + N_p \log_2 M$. For example if $N_t = 16$, $N_r = 4$ and $N_p = 2$, then the total number of combinations will be 120 but the acceptable combinations will be only 64. The length of information bits will be $l_1 = 6$ bits and $l_2 = 4$ bits for $M = 4$ which makes $L = 10$ bits.

The antenna indices chosen for transmission is (1, 4) as shown in Fig. 1, so at a single instant of time the modulated bits will be transmitted from the antennas 1 and 4. The symbol vector is $\mathbf{s} = [s_1\ s_2]^T$, where s_1 is the symbol transmitted from antenna index 1 and s_2 is the symbol transmitted from the antenna index 4 as shown in Table I and Table II.

The symbol transmitted from (1, 4) will therefore be a two row matrix, $\mathbf{s} = [-1+j\ \ 1+j]^T$. Then the transmitted vector will have all the zero values except at positions from where the data was transmitted. So, it will have non-zero value at only first and fourth row and rest all fourteen rows will be zero. The transmitted vector will be given by

$$\boldsymbol{x} = [-1+j\ \ 0\ \ 0\ \ 1+j\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ 0\ \ 0\ \ 0\ \ 0]^T \tag{1}$$

The transmitted vector $\boldsymbol{x}$ is transmitted via a channel matrix $\mathbf{H}$ of dimension N_r X N_t. The received vector $\boldsymbol{y}$ of size N_r X 1 is given by,

$$\boldsymbol{y} = \mathbf{H}\,\boldsymbol{x} + \boldsymbol{n} \tag{2}$$

where, $\boldsymbol{n}$ is the white Gaussian noise vector with mean zero and $\boldsymbol{E}[nn^H] = I_{Nt}$.

Table I Transmit antenna set mapping table

Bits	Antenna Sets
111000	(4,11)
111001	(2,8)
110110	(1,4)
110111	(5,10)
110011	(9,16)

Table II Constellation Mapping Table

Bits	Symbol
00	-1-j
01	-1+j
10	1-j
11	1+j

A summary of various detection methods is discussed below [13]:

A. Maximum Likelihood (ML)

In ML detection technique the parameters are obtained in order to maximize the likelihood of the observations. The basic idea is to calculate the distance between the detected points and the existing points. This distance should be minimized in order to obtain the error as low as possible.

$$\left(\hat{I},\hat{s}\right)=\arg\min_{I\in I,x\in Q}\left\|y-H_I x\right\|_F \tag{3}$$

where, I is the antenna combination used and therefore other components of the channel matrix would be zero. With equation (3), active antenna combination is obtained and then the symbols are detected.

The error probability is found from the probability density function (PDF) of $\boldsymbol{y}$ conditioned on $\mathbf{H}$ and $\boldsymbol{x}$ so as to obtain error as low as possible by using the equation below [13]:

$$p_y(y\,|\,s,I,H)=\frac{1}{\left(\pi\sigma_n^2\right)^{N_r}}\exp\left(-\frac{\left\|y-h_I s\right\|}{\sigma_n^2}\right) \tag{4}$$

Eqn (4) represents the data estimation method.

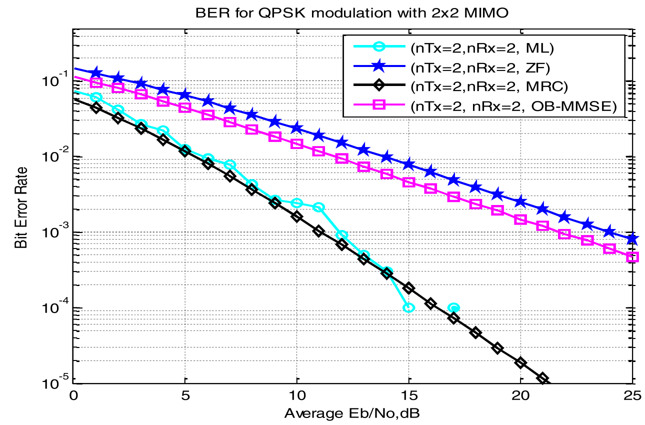

Fig. 2. BER for QPSK modulation with 2*2 MIMO

B. Maximum Receiver Ratio Combining (MRRC)

In MRRC the data received by the receivers are multiplied by a weighing factor so that the high amplitude data is maximised and low amplitude data is minimised and attenuated. Thereafter the data from all the channels are added together to maximise the gain and minimize the noise therefore called as ratio-squared combining. In other words the strong signals are amplified and the weak signals are attenuated. The least square solution using ML and MRC is

$$\hat{s}=\arg\min_{s\in QPSK}\left|\breve{s}-s\right|^2 \tag{5}$$

where the estimated symbol

$$\breve{s}=\left(h^*h\right)^{-1}h^*y \tag{6}$$

The signal is rotated and weighed from every antenna and then the maximum amplitude data is used to estimate the transmitted data.

C. Minimum Mean Squared Error (MMSE)

MMSE is the method in which the basic idea is to minimise the noise power by minimising the mean squared error (MSE) so as to make the Inter-symbol Interference (ISI) as low as possible. The covariance matrix is used to calculate the MMSE of the transmitted symbols using the Bayesian methods.

In this paper, the Ordered-Block Minimum Mean Squared Error (OB-MMSE) is studied and complexity value is calculated. Firstly the pseudo-inverse of channel matrix is taken and then the weighing factors are calculated so as to estimate the correct antenna index. Sorting of values are done to get the accurate indices of active antennas. Then the correct symbols are estimated using the Q-mapping table. In this way, correct symbols are estimated optimally. The complexity value for OB-MMSE and ML detection is calculated to be [9],

$$C_{OB-MMSE} = \frac{1}{L}\left(6N_rN_t + 8N_rN_t + 3N_t + N.N_p\right) +$$

$$\frac{\rho_{avg}}{L}\left(12N_rN_p^2 + 11N_rN_p + 6N_r - 6N_p^2\right) \quad (7)$$

and

$$C_{ML} = \frac{1}{L}\left(6MN_rN_t + 2^L.2N_pN_r + 2^L.6N_r\right) \quad (8)$$

where ρ_{avg} is the average number of block MMSE detected sysmbols.

So, for the assumed number of transmitting and receiving antennas complexity value from equation (7) and (8) is, $C_{OB-MMSE}$ = 137 and C_{ML} = 4249.

Hence, by calculating the complexity values and simulating the results it is observed that among sub-optimal receivers, OB-MMSE gives the optimal results along with low receiver complexity.

D. Zero Forcing (ZF)

In ZF detection technique there should be a prior knowledge of what data has been transmitted from the transmitter. Inverse of the channel matrix is taken which is multiplied with the receiving vector. To calculate $\boldsymbol{x}$, the zero forcing equalizer $\mathbf{W}$ is calculated which satisfies

$$\mathbf{W} = \mathbf{WH} = \mathbf{I} \quad (9)$$

and

$$\mathbf{W} = (\mathbf{H}^H\mathbf{H})^{-1}\mathbf{H}^H \quad (10)$$

III. Simulation Results

We have considered a downlink (DL) situation with two receive antennas and two selected transmit antennas with QPSK as the symbol modulation scheme. A comparison of various detection techniques discussed in previous sections is carried out with the above set-up of the DL and is shown in Fig.2. Given the conditions prevalent in the transmission schemes for a GSM-MIMO system, it is very much evident that the optimal ML detection is difficult to be applied to. Therefore, as deliberated earlier, the sub-optimal schemes are compared with the ML and MRC schemes as a measure of performance.

It is observed that for a given SNR (E_b/N_0) the performance of OB-MMSE is better than that of ZF receiver schemes. This is attributed to the inverse of the channel matrix $\mathbf{H}$ which is required to be computed in case of ZF receiver as given in eqn. (9). However, the system performance in case of ZF receiver improves in terms of better BER if successive interference cancellation scheme is employed. This results from the fact that at each iteration the interference due to other receive paths are eliminated thereby reducing the noise due to interference.

In case of OB-MMSE or more generally in GSM, the transmission of spatial dimension (antenna subset index) and the symbol modulation results in a joint detection of these two parts at the receiver end. Hence it requires an exhaustive search for all possible symbol vectors. This is evident in the plots of Fig.2, where the performance of a regular ML detection or MRC scheme offers better BER performance. Thus we opt for sub-optimal detection schemes.

If 16 transmitting antennas are considered out of which only 2 antennas are active and 4 receiving antennas are present then the complexity value for OB-MMSE technique is 137.6 and that for ML method is 4249.

IV. Conclusion

From the above observation, it may be concluded that ML detection and MRC detection methods provide the best BER performance as compared to OBMMSE and ZF receivers. But taking the spectral efficiency into consideration with reduction in receiver complexity as the priority, OB-MMSE detection method should be chosen for the system. The system becomes further simplified if the information is transmitted only in terms of antenna indices.

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