An Analysis and Detection Results of Spatial Modulation using Modulation Schemes

Anu Johnson
ECE Department
Medi-Caps. Institute of Technology and Management
Indore, Madhya Pradesh

Vibha Tiwari
ECE Department
Medi-Caps. Institute of Technology and Management
Indore, Madhya Pradesh

Abstract—Spatial modulation (SM) is a multiple input multiple output wireless communication system that gives better spectral efficiency. This scheme uses antenna indices and a conventional signal set to convey information. A drawback in SM is its low spectral efficiency. A recently proposed extension (or generalization) of SM, termed generalized spatial modulation (GSM), allows multiple transmit antennas to be active simultaneously. By choosing a combination of total number of transmit antenna elements and number of transmit RF chains, GSM can achieve higher spectral efficiencies than SM. In this paper we are using Maximum Ratio Combining scheme i.e. MRC scheme and ML detection scheme and thus analyzing there BER and reduction in complexity for GSM. We provide an exact BER analysis for Maximum Ratio combining and imperfect channel estimation at the receiver. The BER characteristic of various transmitting and receiving antennas are simulated in MATLAB tool box. It shows that MRC based receiver is best choice for removing ISI and for minimizing the total noise power. ML decoding scheme in the SM system involves joint detection of transmit antenna index and the transmitted symbol. Sphere Decoding becomes essential in order to achieve ML performance while keeping decoding complexity at its minimum. Thus ML performance gives reduced complexity and MRC scheme reduces the BER as the antenna configuration is increased.

Keywords—MRC, ML, SM, GSM, MIMO.

I. INTRODUCTION

Spatial Modulation scheme helps the system to be more spectrum efficient that is to increase the bandwidth of the system. Since the use of smartphone has been increased drastically because of which data traffic increases. For this these networks are being allocated with RF spectrum. Since every year data traffic gets doubled. Spatial modulation (SM) is a multiple input multiple output wireless communication system that gives better spectral efficiency[1]. This scheme uses antenna indices and a conventional signal set to convey information. A drawback of SM is that it has low spectral efficiency. A recently proposed method for comparison is generalization of SM, termed generalized spatial modulation (GSM*)*. It allows multiple transmit antennas to be active at a particular simultaneous time[2]. By comparison and combination of total number of transmit antenna elements and number of transmit RF chains, we can analyze that GSM achieves higher spectral efficiencies than SM. The MIMO which indulge transmission technique plays a vital role in determining achievable system performance. As there are single RF MIMO family and multiple RF MIMO family, SM belongs to single RF MIMO family, [4]. In SM there are number of transmit and receive antennas but only one transmit antenna is active at a time. SM helps the system to reduce the complexity and the cost of multiple antenna schemes. SM can achieve low Complexity transceiver design and high spectral efficiency. Since we can see that there is only one transmit antenna activated at a time for data transmission, so this allows SM to avoid Inter-carrier Interference (ICI). Synchronization among transmission antennas will not be there and it only consists of one RF chain for data transmission [5].

In SM there are number of transmit and receive antennas but only one transmit antenna is active at a time and others remain silent.[7] Data in the input decides to keep which antenna to be active, thus the antenna index carry useful information and thus the spectral efficiency is increased [8]. SM is an extension of conventional modulation technique. If we consider a QPSK modulation scheme which has 4 transmit antennas then these 4 bits are mapped to a symbol. SM technique with a QPSK, defines the first 2 bits to be used as transmit antennas and the last 2 bits are used as conventional QPSK modulation as shown in Figure 1.

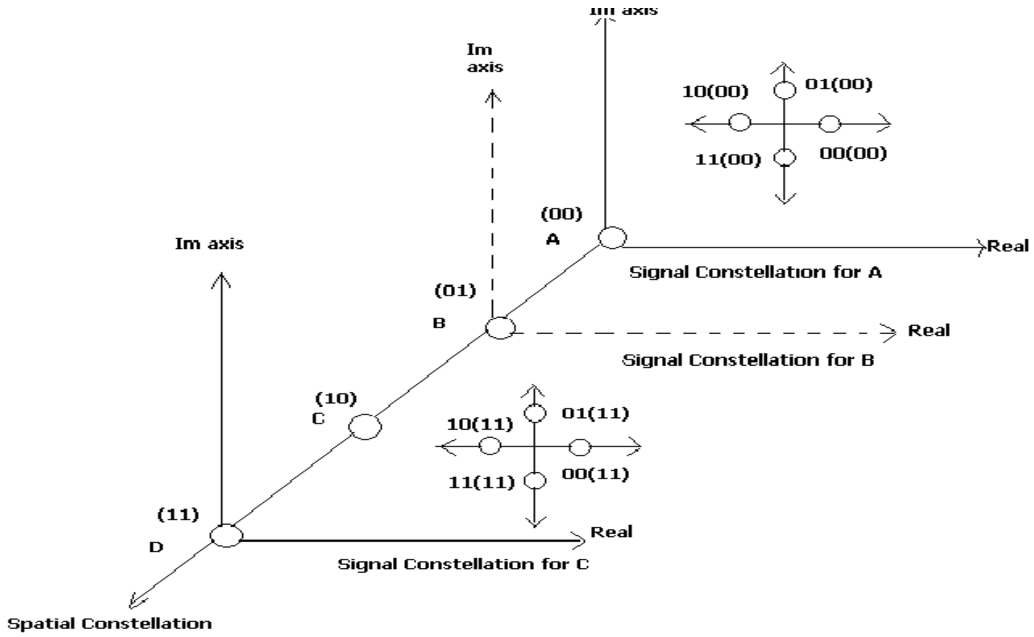

Fig. 1 Spatial Modulation Signal Constellation Scheme

GSM faces challenge with high rate in the detection of the transmitted signal. For large number of transmit antenna elements, maximum-likelihood (ML) detection becomes computationally infeasible. SM has its basic ideology to map a block of information bits to two information carrying unit. One of the information carrying unit is a symbol that is being chosen from a constellation diagram and the other is a unique transmit antenna number that is being chosen from a set of transmit antennas. We have used a Maximum Ratio Combining algorithm and a Maximum Likelihood algorithm at the receiver which are used to retrieve the transmitted block of information bits [9].

In this paper we are comparing Maximum Ratio Combining scheme i.e. MRC scheme and ML detection scheme and thus analyzing there BER and reduction in complexity for GSM. MIMO systems are the key features for achieving capacity gain and diversity gain depending on the channel condition .In this paper, we have also compared these MRC and ML detection scheme by comparatative analysis of the Bit Error Rate performance of various modulation schemes. The simulation results helps us to analyze that it is possible to reduce the BER and helps to obtain good SNR by MRC detection scheme. These modulation scheme are using MRC and ML detection schemes.

II. SYSTEM MODEL

In the below mentioned figure 2 its being depicted that MIMO systems with T transmit and R receive antennas. The spatial mapper maps a certain number of input bits A onto a symbol Be_i where i-th unit vector. This i-th unit vector is having one non zero entry in the i-th position. Modulation symbol B is drawn from any real or complex valued symbol constellation.

The spectral efficiency of a system depends on the number of bits transmitted per channel and on number of data symbol B . It also depend on the signal point constellation applied. Let us consider a QPSK modulation scheme with 4 transmit antennas these 4 bits are mapped to a symbol. The first 2 bits are used to choose transmit antennas and the last 2 bits are used for conventional QPSK modulation. The above modulation scheme has symbol B . The obtained signal from spatial mapper that is Be_i should then be transmitted, thus having always only one active transmit antenna.

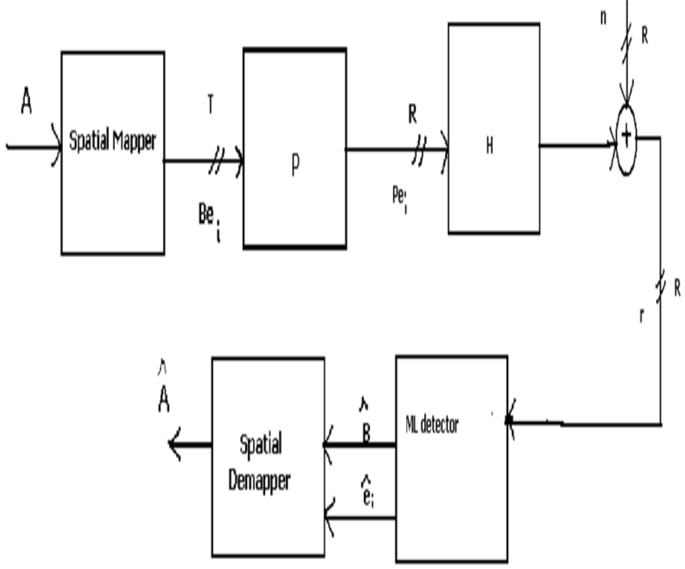

Fig. 2 System Model for GSM using ML Detector

SM detection helps for estimating the index of transmit antenna and the other is symbol demodulation for this antenna at the receiver end. However, because of this in SM only one antenna is activated at a time so that information can be carried through a single channel and other remain silent. Here we use n to denote the complex Gaussian noise vector of R receive antenna $[n_1, n_2, n_3 \ldots\ldots\ldots n_N]$. The received signal y for R receive antennas $[y_1, y_2, y_3 \ldots\ldots\ldots y_N]$ at one time slot is denoted by,

$$Y = \mathrm{H}x + n \tag{1}$$

where, x is modeled as transmitted vector and H is a complex channel matrix. The channel fading coefficients between T transmit antennas and R receive antennas are denoted by h_{mn} as shown in (2). Here, we will assume H as a Rayleigh flat fading channel and it is known to the receiver. Let us suppose that multiple outputs are located at the input of receiver and the multiple inputs are located at the input of transmitter. Thus, the channel with R outputs and T inputs is represented in matrix form as

$$H = \begin{matrix} h_{1,1} & h_{1,2} & \cdots & \cdots & h_{1,T} \\ h_{2,1} & h_{2,2} & \cdots & \cdots & h_{2,T} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ h_{R,1} & \cdots & \cdots & \cdots & h_{R,T} \end{matrix} \tag{2}$$

In the below mentioned figure 3, it depicts MIMO systems with T transmit and R receive antennas. Figure depicts the spatial mapper which maps a certain number of input bits A onto a symbol Be_i where i-th unit vector consist of one non zero entry in the i-th position. Modulation symbol B is drawn from any real or complex valued symbol constellation. P refers for precoding matrix. In this there is a general beam forming vector B which consist of a codebook depended on first input bits rather than a unit vector e_i. Thus signal is given by Be_i and the symbol B is not transmitted necessarily only on one single antenna element. As we can see in Figure 2 the output of conventional mapper is multiplied with a precoding matrix $P = [P_1 \ldots\ldots P_T]$. This precoding matrix represents the codebook of available beamforming vectors. If P is chosen as the identity matrix then generalized scheme reduces to conventional spatial modulation.

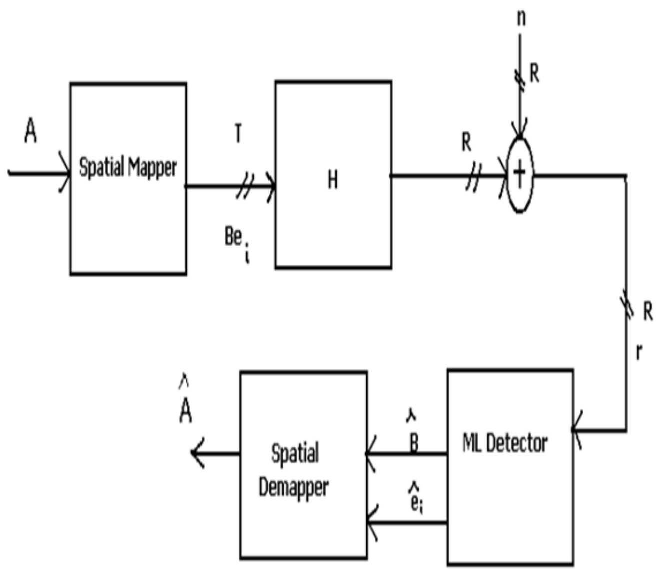

Fig. 3 System Model for SM using ML Detector

Detection Algorithm used for Spatial modulation and Generalized Spatial modulation system are:

A. ML Detection

Maximum Likelihood estimation helps to estimates the statistical models parameter. When a ML decoder is being introduced under a low complexity channel then it depends on transmitted symbol and on the indices of transmit antenna.ML detection can also be applied on an unconstrained channel. The complexity of this channel increases as it depends on overall transmit antenna and modulated symbol.

If we want to reduce the complexity for that can be achieved by reducing candidate. Unified approach for the estimation of Maximum likelihood is achieved by normal distribution and by many other problems. When we apply statistic to this data set and give a statistical model Maximum Likelihood provide estimates for the models parameter. maximum likelihood select values of model parameter can be achieved by giving a fixed set of data. However because of this observed data gets greatest probability.

However, in Spatial Modulation scheme only one transmit antenna being activated for data transmission at any signaling time instant. Therefore, there is only one nonzero value in the vector, which is given as

$$X = [0, \ldots\ldots\ldots, 0, v, 0, \ldots\ldots\ldots 0]^T \tag{3}$$

where v is a complex symbol from the signal set S with $|S| = T$ and the received vector is symbolized by Y. The channel matrix H is $R \times T$ fading matrix with $(i, j) - th$ entry $h_{i,j}$ denoting the normalized complex fading gain from transmit antenna j to receive antenna i, n refers for noise vector.

We have already assumed that the receiver already knows the channel matrix H for SM channel and the transmitted symbol vector that is (B,e_i) estimated by maximum likelihood detector [10].

$$[B,e_i] = \arg\min \| Y - Hx \|^2 \quad (4)$$

B. MRC Detection

Diversity combining method is also termed to be as MRC. This is made proportional to RMS value of signal and itsn inversely proportional to that channels mean square noise level. Various proportionality constants are used for these channels. We can combine the signal from multiple diversity branches through various techniques.

In MRC each signal branch is multiplied by a weight factor which is being proportional to the signal amplitude. This means that the branches with strong signal are amplified while the branches with weak signal are attenuated. They are also termed to be as ratio squared combining and predetection combining. MRC is optimal combiner for AWGN channel. However we are well known that MRC enhances strong signal while attenuate weak signals. This is same as type of filtering and signal weighing used in matched filter.

Antenna index estimation scheme is being proposed for antenna index estimation by MRC detection which is given below:

$$g_j = h_j^H \times y \quad (j = 1,2,\ldots\ldots T) \quad (5)$$

$$t = \arg\max\left(\left\|g_j\right|\right]_{j=1,2,\ldots\ldots T}) \quad (6)$$

$$X_q = Q(g_i) \quad (7)$$

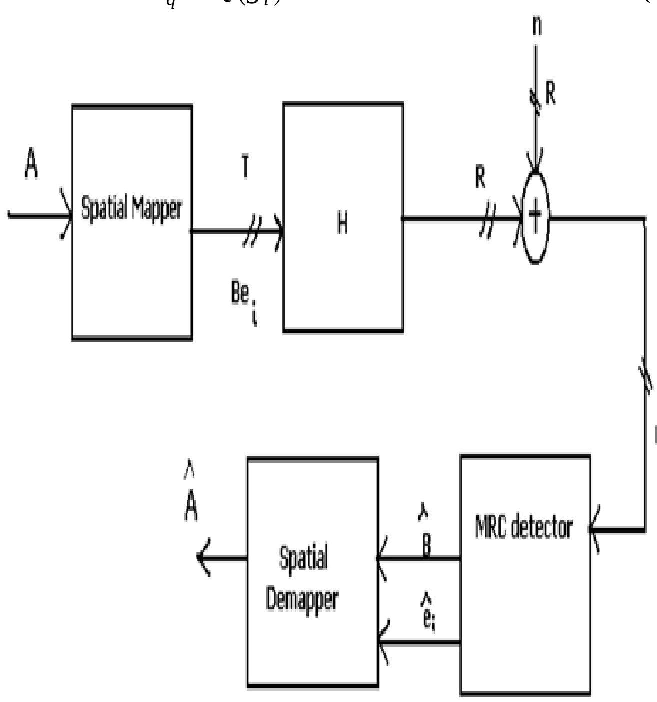

Fig. 4 System Model for SM using MRC Detector

Where, $Q(.)$ is being symbolized as Constellation Quantization function based on obtained t and x_q demodulation data is being evaluated from demapping. The above algorithm would work under the same conditions. By substituting (5) in (1) and neglecting noise we get,

$$g_j = h_j h_t x_q \quad (8)$$

by putting this value in (6) we will find that we want to get correct antenna index. So, we require

$$\left|h_t{}^\wedge \mathrm{H}_t\right| = \left\|h_t\right\| \geq \left|h_j{}^\wedge \mathrm{H} h_t\right| \quad (j = 1,2,\ldots\ldots M) \quad (9)$$

III. PERFORMANCE ANALYSIS

In the following, we have present selected performance results to illustrate that the average BERs works better with simulated values and the performance of the system can be improved by selecting appropriate codebook matrix P .

In the below figure 5 we have experimented the BER for 16 QAM for GSM using MRC at the detector end. This MRC detection helps to boost strong signals and it attenuates weak signal. For the selection of an appropriate symbol B a standard gray mapping is used. For better results we have used an SM system which consist of M_t transmit antennas, M_r receive antennas and M modulation schemes. Thus by this we can evaluate better result for 16 QAM modulation technique.

At 5 dB SNR 16 QAM results in BER of $2.513 * 10^{-1}$, at 10 dB SNR the BER is evaluated as $9.837 * 10^{-2}$, at 15 dB SNR the BER is evaluated as $1.217 * 10^{-2}$ and at 20dB SNR the BER is evaluated as $1.1 * 10^{-3}$.

In this section, we present simulation result of BER performance achieved by SM for various modulation schemes as given below in figure 3. We compare the result of MRC and ML for various modulation schemes like BPSK and QPSK which is being depicted below in figure 4. We also compare the performance of various modulation schemes like BPSK, QPSK, 8-PSK, 4-QAM and 8-QAM for evaluating better performance as shown in Figure 3. For notation purpose we have used a SM system with M_t transmit antennas, M_r receive antennas and M modulation schemes.

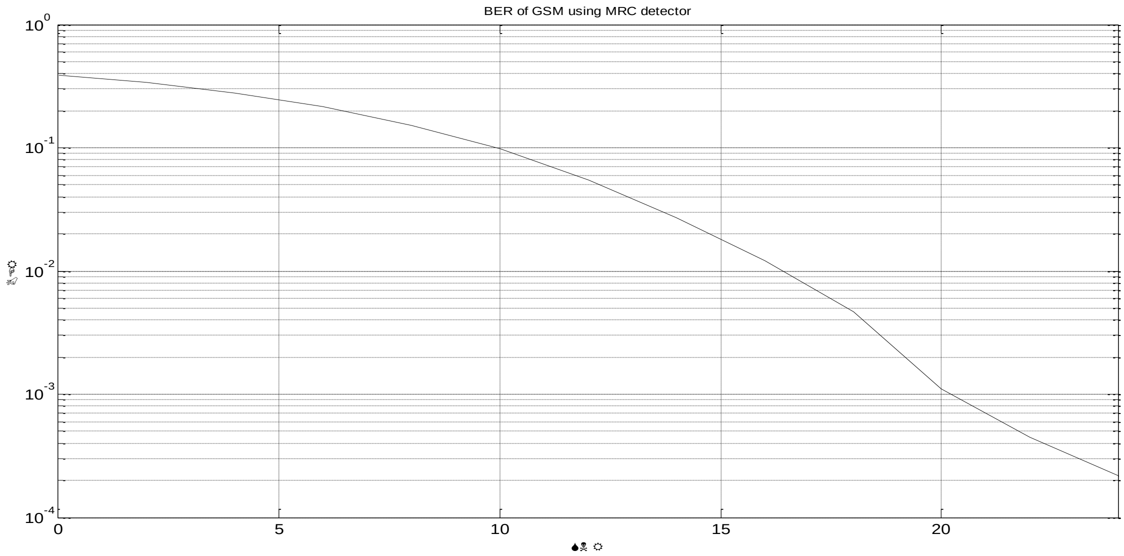

Fig. 5 BER Performance of GSM using MRC Detector for 16-QAM

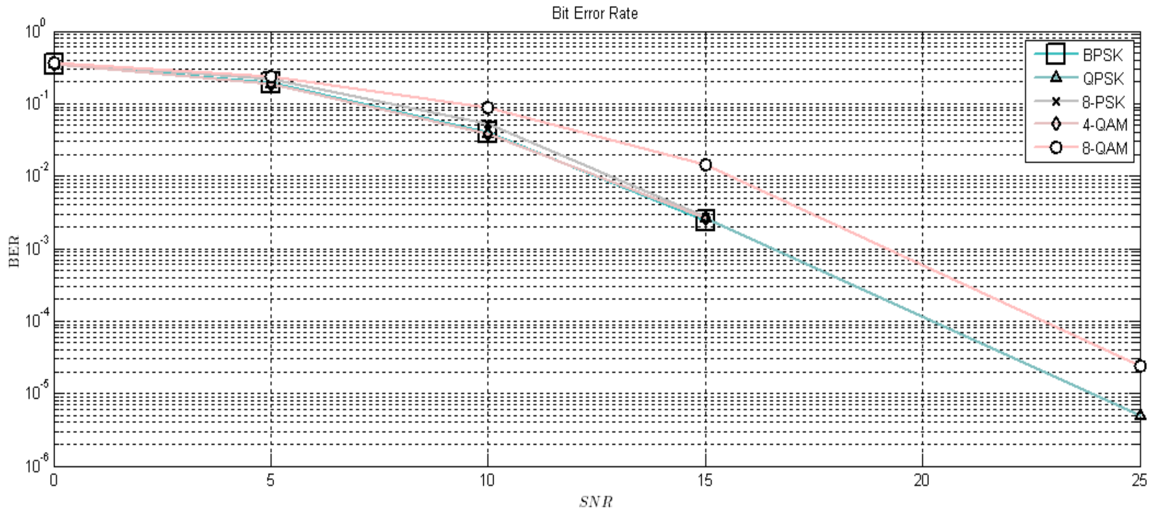

Fig. 6 BER Performance for Different Modulation Schemes

In Figure 6 we have shown compared the BER of certain modulation schemes like BPSK, QPSK, 8-PSK, 4-QAM and 8-QAM in SM. At high SNR, 4-QAM gives excellent results as far as BER is concerned. It has been observed from the results that detection technique like MRC and ML detection technique helps BPSK scheme to perform better as compared to others.

At 5dB SNR, BER for QPSK gives $1.897*10^{-1}$, while BPSK is observed to be $1.906*10^{-1}$, 8-QAM gives $2.332*10^{-1}$, 4-QAM gives $1.893*10^{-1}$ and 8-PSK gives $2.176*10^{-1}$.

At 10dB SNR, BER for QPSK gives $3.852*10^{-2}$, BPSK is observed to be $3.956*10^{-2}$, 8-PSK gives $5.19*10^{-2}$,4-QAM gives $3.84*10^{-2}$ and 8-QAM gives $8.814*10^{-2}$. In BPSK the modulation rate is chosen as M=2, for QPSK and 4-QAM the modulation rate is M=4 and for 8- QAM and 8- PSK we have chosen Modulation rate as M=8. Thus after the comparison, its being evaluated that 4-QAM give optimal result.

We have also compared these detection techniques for ML and MRC as for BPSK and QPSK modulation schemes. At 5 dB SNR, BER for ML QPSK is observed to be $1.795*10^{-1}$, MRC QPSK is observed to $1.895*10^{-1}$, ML BPSK is observed to be $1.263*10^{-1}$ and MRC BPSK is observed to be $1.906*10^{-1}$. At 10 dB SNR, BER for ML BPSK is being observed as $1.505*10^{-2}$, MRC BPSK is observed as $3.956*10^{-2}$, MRC-QPSK is observed to be $3.852*10^{-2}$ and ML QPSK is observed to be $2.755*10^{-2}$.

We have evaluated and compared the results of various modulation scheme at various detector end and the resulted analysis is BPSK provides better results at both detector end. BER analysis evaluated is better for BPSK and QPSK modulation scheme when we detect it at the detector end using MRC and ML scheme as shown in Figure 7. The SNR of BPSK and QPSK using MRC and ML is given below. By this analysis the signals at various points are being evaluated so as a better system performance can be evaluated.

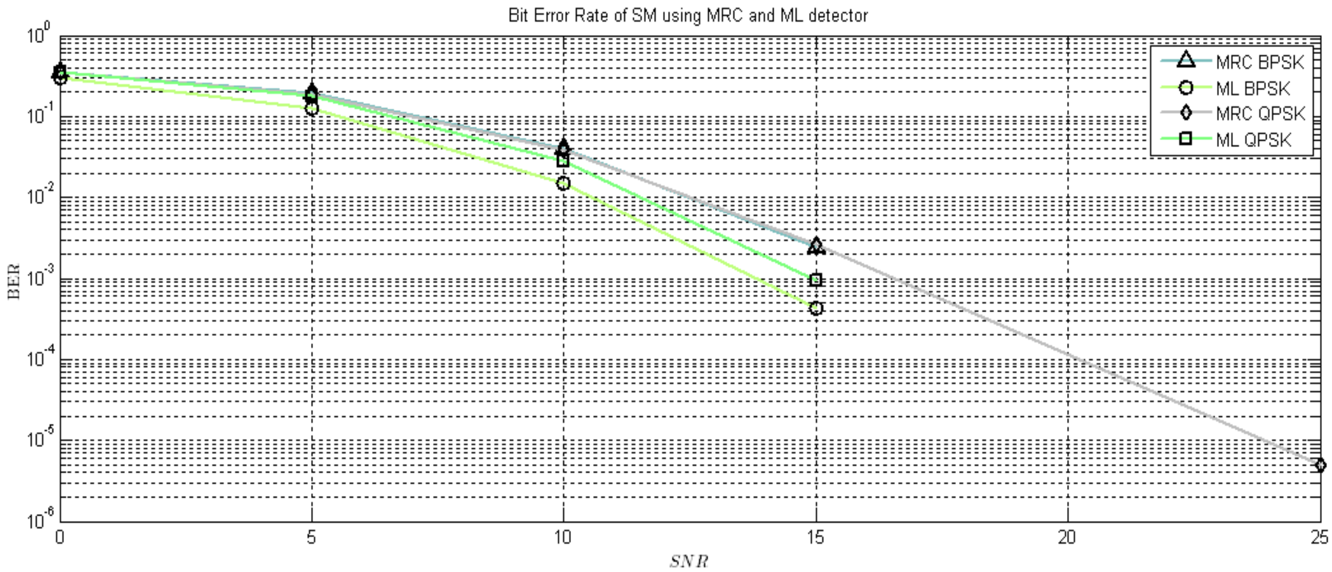

Fig. 7 BER Performance of SM using MRC and ML Detector

IV. CONCLUSION

We have used two detection technique MRC and ML for obtaining optimized detection technique for Spatial Modulation technique. This technique is used along with 16-QAM, QPSK and BPSK technique. We have used Spatial Modulation technique along with BPSK, QPSK and QAM modulation techniques to increase the spectrum efficiency of the system. In this paper we are using Maximum Ratio Combining scheme i.e. MRC scheme and ML detection scheme and thus analyzing there BER and reduction in complexity for GSM. We provide an exact BER analysis for Maximum Ratio combining and imperfect channel estimation at the receiver. Hence performance evaluation of SM and GSM are being compared to evaluate better results. Thus, simulation results were shown to be in with BERs and hence the proposed spatially modulated approach can yield SNR gains in the order of several dBs.

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