© 2017 IJEDR | Volume 5, Issue 4 | ISSN: 2321-9939

# Performance of GSM-MIMO With Various Modulation Techniques

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***Abstract*— In this paper, a generalized spatial modulation (GSM) is described. Generalized spatial modulation (GSM) solve the issue of SM that the transmit antennas needs to be power of 2. Block of information bits of constellation symbol and spatial symbol are mapped in GSM. Combination of transmit antennas activated at every instance is known as spatial symbol. Actual combination of active transmit antenna is being decided by random incoming data stream. In SM where only a single transmit antenna is activated at each instance of time whereas in GSM to increase spectral efficiency it uses base-two logarithmic antennas combinations. As compared to SM, GSM reduces number of communicating antennas. The performance of GSM is analyzed in this paper, and BER performance is derived. In addition, an algorithm to optimize the antenna combination selection is proposed. The result is analyzed in terms of comparison of GSM with traditional SM. GSM shows same spectral efficiency as SM provides but it reduces number of antennas. GSM-MIMO can outperform multiuser SM-MIMO by about 2 to 9 dB at a bit error rate of $10^{-3}$.**

***Index Terms*— Multiple Input Multiple Output (MIMO), GSM, STBC, BPSK, QPSK, QAM, Spatial modulation, outage probability.**

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## I. INTRODUCTION

Multiple-antenna systems are fast becoming a key technology for modern wireless systems. They offer improved error performance and higher data rates, at the expense of increased complexity and power consumption. Spatial modulation (SM) is a recently proposed approach to multiple-input-multiple-output (MIMO) systems which entirely avoids inter-channel interference, requires no synchronization between the transmit antennas and achieves a spatial multiplexing gain. This is performed by mapping a block of information bits into a constellation point in the signal and spatial domains [1].

In SM, the number of information bits, $\ell$, that are encoded in the spatial domain can be related to the number of transmit antennas $N_t$ as $N_t = 2^{\ell}$. This means that the number of transmit antennas must be a power of two unless fractional bit encoding or generalized SM are used. SM offers an intrinsic flexibility to trade off the number of transmit antennas with the modulation order in the signal domain to meet the desired data rate. It should be noted that SM is shown to outperform other point-to-point MIMO schemes in terms of average bit-error-ratio (ABER) [2].

In the single user scenario, only a single transmit antenna is active at any instance, this avoids the need for complicated interference cancellation algorithms at the SM receiver.

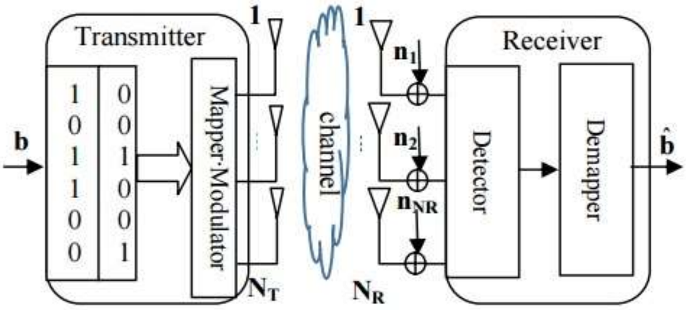

Figure 1 Block diagram of the proposed GSM MIMO system

In addition, unlike other MIMO schemes shown in fig.1 the number of receive antennas is independent of the number of transmit antennas. [3]

MIMO techniques can also be used in relaying networks to improve the diversity, provide multiplexing gains and aid in interference cancellation. To this extent, the orthogonal decode and forward (DF) algorithm decodes the received signal at the relay, then re-encodes and retransmits this information, establishing a regenerative system. Outage probabilities, mutual information calculations and transmit diversity bounds for orthogonal amplify and forward (AF) and DF relaying are derived in paper [4].

Table 1 Comparison of MU-MIMO VS SU-MIMO

| **Feature** | **MU-MIMO** | **SU-MIMO** |
|---|---|---|
| No. of user communicate with Base station. | The base station is able to separately communicate with multiple users. | Base station communicates with a single user. |
| Data rate | Using MU-MIMO provides capacity gain and more data rate. | Provides increased data rate for the single user. |
| Key advantage | Multiplexing gain. | Interference reduction |
| Data throughput | MU-MIMO provides a higher throughput when the signal to noise ratio is high. | Provides a higher throughput for a low signal to noise ratio. |
| Channel State Information | Perfect CSI is required. | No CSI needed. |

The remainder of this paper is organized as follows. In Section 2, GSM and SM system models along with the channel model are introduced. In Section 3, the generalized closed-form expression for the ABER performance is derived in the presence of CSEs and assuming correlated and uncorrelated fading channels. Finally, the results are presented in Section 4, and the paper is concluded in Section 5.

## II. SYSTEM MODEL

In space modulation, all active transmit antennas send the same complex symbol. Hence, a set of antenna combinations can be formed, and used as spatial constellation points. In GSM the number of active antennas $N_u$ is constant. Therefore, the number of possible antenna combinations is $\binom{N_t}{N_u}$, where$N_t$ is the number of transmit antennas, and $\binom{\cdot}{\cdot}$denotes the binomial operation. However, the number of antenna combinations that can be considered for transmission must be a power of two. Therefore, only $\eta\ell = \left\lfloor log_2 \binom{N_t}{N_u} \right\rfloor$ combinations, can be used, where $\eta GSM$ $\lfloor \cdot \rfloor$ is the floor operation. Thus, the maximum number of bits that can be transmitted using GSM is given by [5],

$$\eta GSM = \eta\ell + \eta s = \left\lfloor log_2 \binom{N_t}{N_u} \right\rfloor + log_2 M \qquad (1)$$

$N_u$=Total active antenna
$N_t$=Total no. of antenna
M=size of constellation diagram

### *Large-scale propagation effects*

The path loss is an important effect that contributes to signal impairment by reducing its power. The path loss is the attenuation suffered by a signal as it propagates from the transmitter to the receiver. The path loss is measured as the value in decibels (dB) of the ratio between the transmitted and received signal power. In general, the path loss is characterized by a function of the form in equation.

$$\Gamma dB = 10\, \nu log\, (d/d0) + c \qquad (2)$$

Where Γ dB is the path loss Γ measured in dB, d is the distance between transmitter and receiver, ν is the path exponent, c is a constant, and d0 is the distance to a power measurement. [6]

### *MIMO spatial multiplexing*

To take advantage of the additional throughput capability, MIMO utilizes several sets of antennas. In many MIMO systems, just two are used, but there is no reason why further antennas cannot be employed and this increases the throughput. In any case for MIMO spatial multiplexing the number of receive antennas must be equal to or greater than the number of transmit antennas.[6]

To take advantage of the additional throughput offered, MIMO wireless systems utilize a matrix mathematical approach. Data streams $t_1$, $t_2$, tn can be transmitted from antennas 1, 2,…n. Then there are a variety of paths that can be used with each path having different channel properties. To enable the receiver to be able to differentiate between the different data streams it is necessary to use. These can be represented by the properties $h_{12}$, travelling from transmit antenna one to receive antenna 2 and so forth. A three transmit, three receive antenna system a matrix can be set up as shown in (3), (4), (5).

$$r_1 = h_{11}\, t_1 + h_{21}\, t_2 + h_{31}\, t_3 \qquad (3)$$

$$r_2 = h_{12}\, t_1 + h_{22}\, t_2 + h_{32}\, t_3 \qquad (4)$$

$$r_3 = h_{13}\, t_1 + h_{23}\, t_2 + h_{33}\, t_3 \qquad (5)$$

Where $r_1$ = signal received at antenna 1, $r_2$ is the signal received at antenna 2 and so forth. In matrix format this can be represented as shown in (6).

$$[R] = [H] \times [T] \qquad (6)$$

To recover the transmitted data-stream at the receiver it is necessary to perform a considerable amount of signal processing. First the MIMO system decoder must estimate the individual channel transfer characteristic hij to determine the channel transfer matrix. Once all of this has been estimated, then the matrix [H] has been produced and the transmitted data streams can be reconstructed by multiplying the received vector with the inverse of the transfer matrix as shown in (7).

$$[T] = [H]^{-1} \times [R] \qquad (7)$$

This process can be likened to the solving of a set of N linear simultaneous equations to reveal the values of N variables. In reality the situation is a little more difficult than this as propagation is never quite this straightforward, and in addition to this each variable consists of an ongoing data stream, this nevertheless demonstrates the basic principle behind MIMO wireless systems. [7]

## III. METHODOLOGY

Figure 2 Shows the considered MIMO system with M transmit and N receive antennas. The (conventional) spatial mapper maps a certain number of input bits **b** onto a vector symbol q**e**i, where **e**i = [0...0 1 0...0] T denotes the i-th unit vector having one non-zero entry at the i-th position.
The modulation symbol q can be drawn from any real- or complex valued symbol constellation.
For illustrating the basic principle in detail, an exemplary mapping process shown in Fig.2 for a MIMO system with four transmit antennas and a QPSK constellation [8].

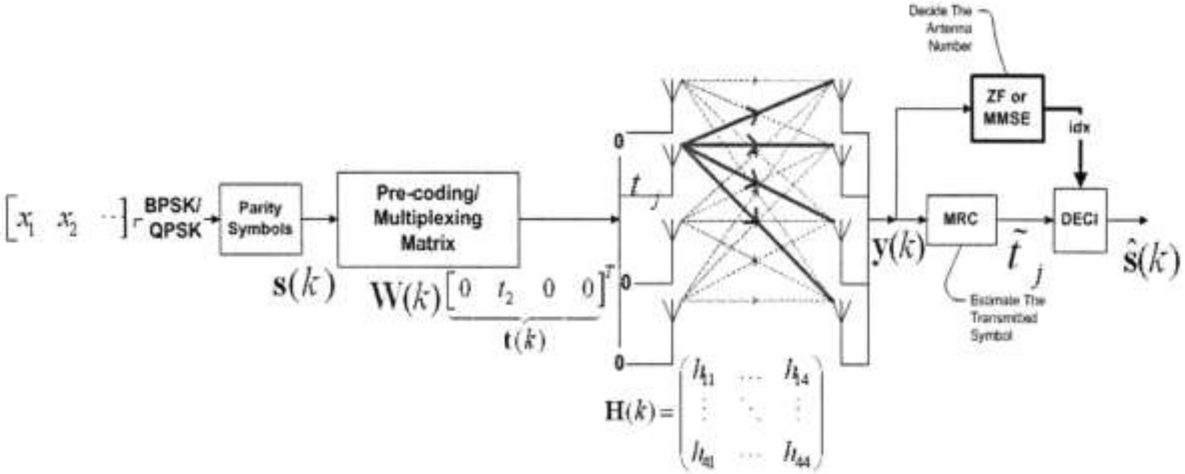

Figure 2 MIMO system with M transmit and N receive antennas

At every transmission interval, four bits are taken from the input stream, where the first 4 bits are used for selecting a unit vector **e**i and hence one out of four available antennas whereas the other 2 bits are mapped to a complex QPSK symbol q.
In the case of conventional spatial modulation as introduced in [2], the signal q**e**i would then be directly transmitted, thus having always only one active transmit antenna.
The number of simultaneously transmitted bits per channel use or equivalently the spectral efficiency is clearly given by (8)
$\eta = \eta symb + log2 (M)$ *(8)*
Where ηsymb denotes the number of bits per data symbol q and depends on the applied signal point constellation.
As a generalization, a general beamforming vector **p**i is selected from a given codebook based on the first input bits rather than a unit vector **e**i. Hence, the actual transmit signal is generally given by q**p**i and the symbol q is not necessarily transmitted over only one single antenna element.
This approach can be easily implemented by multiplying the output of the conventional spatial mapper with a precoding matrix **P** = [**p**1, ..., **p**M] as depicted in Figure 4.1,which in fact represents the codebook of available beamforming vectors. Clearly, if **P** is chosen as the identity matrix of size M, our generalized scheme reduces to conventional spatial modulation as a special case. Besides, it is quite obvious that the linear transformation done by **P** needs to be invertible (i.e. det (**P**) = 0) and that the total mean transmit power must not be affected by **P** [9].
In the following, It is assumed that the vector **s** = q**p**i is transmitted through a correlated frequency-flat Rayleigh fading channel **H** = $\mathbf{A}^H\mathbf{H}_W\mathbf{B}$, where the matrices **A** and **B** are the square roots of the correlation matrices $\mathbf{R}_{rx} = \mathbf{A}^H\mathbf{A}$ and $\mathbf{R}_{tx} = \mathbf{B}^H\mathbf{B}$, respectively.
Furthermore, the entries of $\mathbf{H}^W$ are modelled as independent, complex Gaussian RVs according to CN (0, 1). It is well-known that autocorrelation matrix $R_{HH}$ of H is then given by $R_{HH} = Rtx^* \otimes Rrx$. The elements of the AWGN vector n are assumed to be independent and identically distributed according to CN (0, $\sigma^2$ n).
The received signal vector r is then given by r = $H_s$ + n and a maximum likelihood (ML) detector estimates the transmitted symbol vectors. Due to the insertion of the pre-filter matrix P, generally more than one TX antenna is active per point in time, resulting in a higher transmitter and receiver complexity.
However, this approach has the big advantage that the available transmit power can be equally distributed among all antenna elements while conventional spatial modulation assigns the power to only one antenna element. This has for example the potential to significantly reduce the requirements on the used amplifiers.
In fact, if P is chosen as a discrete Fourier transform matrix every antenna element is always active and transmits at the same constant power level. Clearly, without spatial correlation at the transmitter-side, any unitary matrix P achieves the same performance as conventional spatial modulation since the statistical properties of $H_W$ and $H_W$ P are identical [10].

## IV. RESULTS

The BER performance versus signal to noise ratio (SNR) for $M_t$= 8, 16, 32 are depicted in below Fig. 3. The performance of GSM is nearly identical to the performance of SM. The better performance of SM is mainly due to the higher probability of error when detecting two active antennas instead of only one. However, SM requires more than twice the number of transmit antennas to achieve the same spectral efficiency as compared to GSM. The result also validates the derived analytical bound and shows that, indeed, it is very tight. The results for $M_t$= 8, 16, 32 are depicted in Fig.3 GSM with different $M_t$have nearly the same performance, with a slightly better performance of $M_t$ = 32 at high SNR.

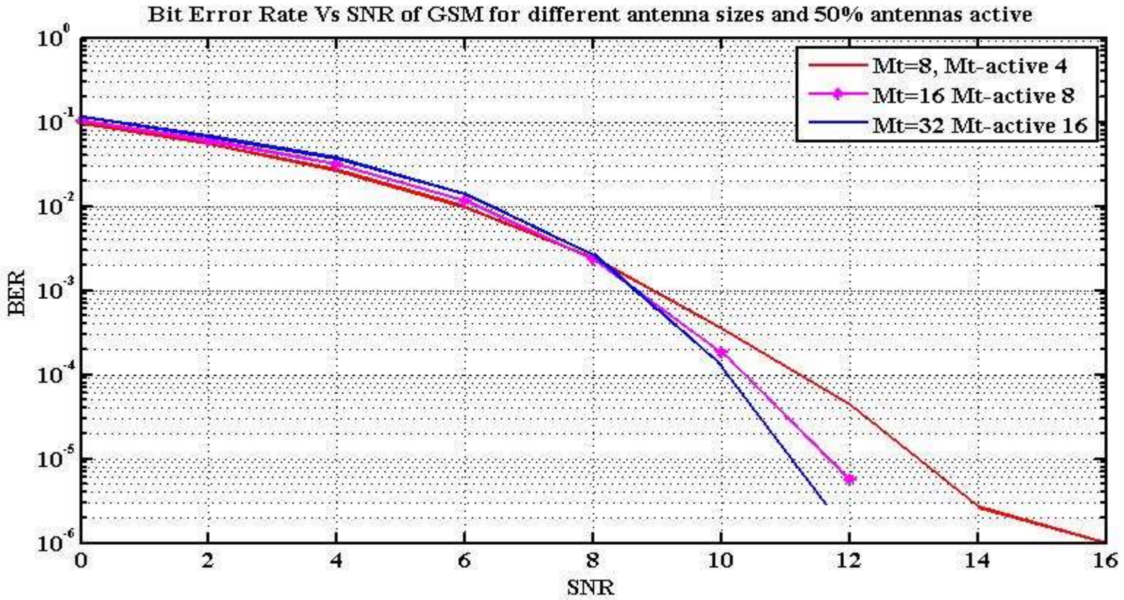

Figure 3 BER vs SNR of GSM for different antenna sizes with 50% antenna active

In below Fig. 4 BER performance of the following two different systems with$N_t$= 16 out of only 50% are active. System 1 shows Conventional multiuser GSM MIMO with $N_t$= 16, with 16, 32, 64-QAM.System 2 shows SM MIMO with $N_t$=16 with16, 32, 64-QAM.Another observation in Fig. 5.6 is that multiuser GSM-MIMO system. System 1 performs better than multiuser SM-MIMO system. System 2 This is because, though GSM-MIMO uses two spatial streams like conventional MIMO, its alphabet size is smaller than that in conventional MIMO. Here when compare 64-QAM GSM with 64-QAM SM the GSM outperform by 16dB at BER of $10^{-3}$. 16-QAM GSM outperform by 10dB when compare with 16-QAM SM.

Table 1 Comparison of BER vs SNR of GSM for different antenna sizes with 50% antenna active

| MIMO parameters (Reported) | Reported | | Achieved | | SNR Difference (dB) |
|---|---|---|---|---|---|
| | BER | SNR | BER | SNR | |
| Mt=8, Active=4 | $10^{-4}$ | 15 | $10^{-4}$ | 11 | SNR diff.1=4 |
| | $10^{-5}$ | 17 | $10^{-5}$ | 13 | SNR diff.2=4 |
| Mt=16, Active=8 | $10^{-4}$ | 13.8 | $10^{-4}$ | 11.3 | SNR diff.1=2.5 |
| | $10^{-5}$ | 16 | $10^{-5}$ | 12 | SNR diff.2=4 |
| Mt=32, Active=16 | $10^{-4}$ | 12.8 | $10^{-4}$ | 10 | SNR diff.1=2.8 |
| | $10^{-5}$ | 14.2 | $10^{-5}$ | 11.6 | SNR diff2.=-2.6 |

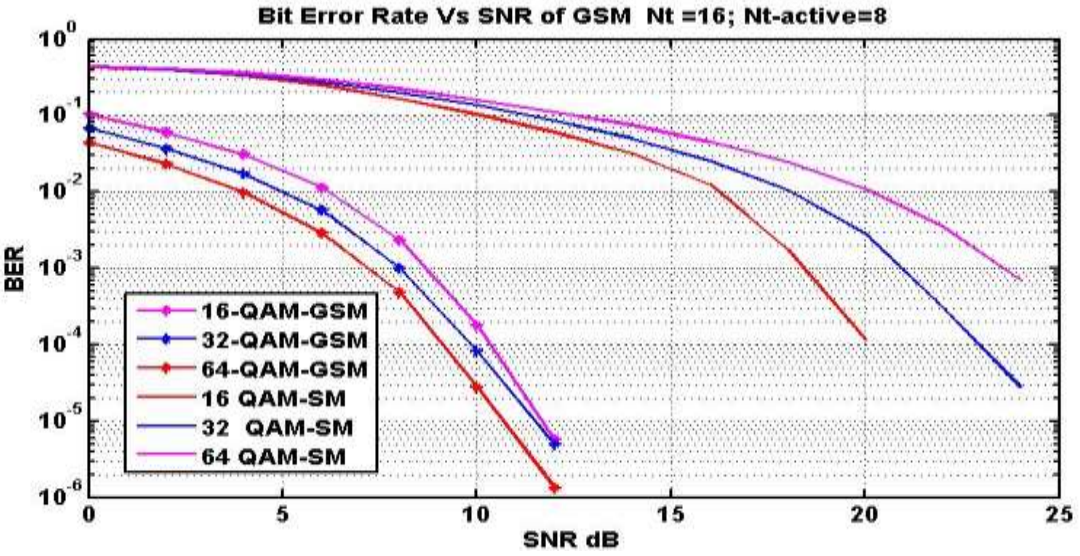

Figure 4 Comparison of GSM vs SM with different QAM

Table 2 Comparison of SM vs GSM on different type of M

| Size of M | BER of SM-QAM | SNR of SM-QAM | BER of GSM-QAM | SNR of GSM-QAM | SNR Difference(dB) |
|---|---|---|---|---|---|
| 4 | $10^{-3}$ | 18 | $10^{-3}$ | 9 | SNR diff.1=9 |
| | $10^{-4}$ | 20 | $10^{-4}$ | 10.5 | SNR diff.2=9.5 |
| 16 | $10^{-3}$ | 22 | $10^{-3}$ | 8 | SNR diff.1=8 |
| | $10^{-4}$ | 24 | $10^{-4}$ | 10 | SNR diff.2=14 |
| 64 | $10^{-3}$ | 24 | $10^{-3}$ | 8 | SNR diff.1=16 |
| | $10^{-4}$ | ---- | $10^{-5}$ | 10.2 | ----- |

## V. CONCLUSION

It is investigated that generalized spatial modulation (GSM) for multiuser communication on the uplink in large-scale MIMO systems. We derived an analytical upper bound on the average bit error probability in multiuser GSM-MIMO systems with ML detection. The bound was shown to be tight at moderate to-high SNRs. Numerical results showed that, for the same spectral efficiency, multiuser GSM-MIMO can outperform conventional multiuser MIMO by several dBs.

It is proposed that low-complexity algorithms for multiuser GSM-MIMO signal detection and channel estimation at the BS receiver based on message passing. The performance of these proposed algorithms in large-scale GSM-MIMO systems with tens of users and hundreds of BS antennas showed that multiuser GSM-MIMO can outperform conventional multiuser MIMO.

The SNR advantage of GSM-MIMO over conventional MIMO is attributed to the following reasons: because of the spatial index bits, to achieve the same spectral efficiency, GSM-MIMO can use a lower-order QAM alphabet compared to that in conventional MIMO, and (*ii*) to achieve same spectral efficiency and QAM size, conventional MIMO will need more spatial streams per user which results in increased spatial interference.

This performance advantage along with low RF hardware complexity makes large-scale multiuser GSM-MIMO very attractive. We further note that the SM concept has recently been validated with the aid of experimental activities in indoors and outdoors. These practical advancements in SM and the performance advantage in GSM-MIMO suggest that large-scale multiuser GSM-MIMO is an attractive technology.

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