Performance Analysis of Spatial Modulation over Weibull Fading Channels

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Abstract: - Ascertaining the importance of the recently proposed spatial modulation, we study its performance in Weibull multipath fading channels. Closed form integral expressions for calculating the symbol error rate of spatial modulation (SM) in independent, not necessarily identical Weibull fading channels are derived. Simulation and the analytical results, considering different transmission scenarios, are very close over a wide range of signal-to-noise ratio (SNR) values.

Key-Words: -Spatial modulation, Weibull fading, symbol error rate

1 Introduction

Multiple antennas at the transmitter and at the receiver are used to increase the spectral efficiency and/or diversity gain. However, simultaneous transmission from multiple antennas causes high inter-channel interference and inter-antenna synchronization [1]. SM has been proposed by [2] to avoid the inter-channel interference and the need for antenna synchronization. This is achieved by making one transmitting antenna active at any signaling time interval and employing the antenna index as additional source of information [2].

The performance of SM considering suboptimal receiver, was investigated in [2]. They presented a closed form expression to calculate symbol error rate (SER) of SM in identical and independent Rayleigh fading channels. Also, they presented simulation results of SM over Rician fading channels considering channel correlation. In [3] performance improvement by 4 dB has been achieved when using maximum likelihood (ML) optimum hard decision receiver, compared to the suboptimal one presented in [2]. A ML optimum soft decision decoding algorithm was proposed in [4]. It stated that the soft decision can improve the performance by 3 dB, compared to hard decision decoding.

Authors in [5] analyzed the performance of SM in correlated and uncorrelated Nagakami-m fading considering the suboptimal receiver. A closed form expressions to calculate the SER of SM were derived.

It can be noticed that none of the above mentioned work considered the Weibull fading channel despite the fact that it exhibits an excellent fit to fading channel measurements for indoor as well as outdoor environments [6,7]. In this paper we study the performance of SM over Weibull fading channels. Exact integral expressions for the SER performance of M-QAM SM system are derived for the suboptimal receiver. Simulation and analytical results are closed to each other.

The rest of the paper is organized as follow: Section 2 describes the system model while section 3 presents the performance analysis. Section 4 discusses the achieved results. Finally, section 5 concludes the work.

2 System Model

A general spatial modulation MIMO wireless system consists of N_t transmit and N_r receive antennas as shown in Figure 1. A detailed description of spatial modulation; how it works, its advantages and disadvantages can be found in [8].

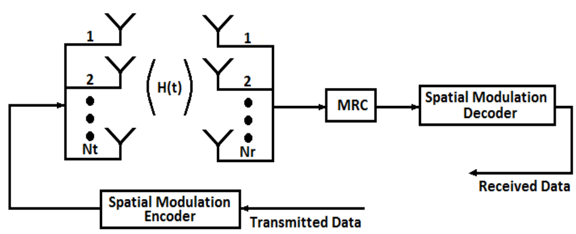

Figure 1 Spatial modulation system model

The input binary data is divided into symbols of n bits, where $n = \log_2(MN_t)$ and M is the modulation level. The resultant symbols is mapped into a vector: $x = [x_1\ x_2 \dots x_{N_t}]$, assuming unity channel gain and because one antenna is active, the output of the SM mapper can be written as: $x_{jq} = [0\ 0 \dots x_1\ 0\ 0 \dots 0]$ for the jth active transmit antenna and the qth symbol from M-ary modulation [3, 5].

The signal is transmitted over a MIMO channel $H = [h_1\ h_2 \dots h_{Nt}]$ and the corresponding channel vector from the jth transmit antenna to all receive antennas $h_j = [h_{1,j}\ h_{2,j} \dots h_{Nr,j}]^T$ [3,5]. Each channel in the system is modeled as a frequency nonselective slowly Weibull fading channel.

The received signal $y = Hx + n$ where $n = [n_1\ n_2 \dots n_{Nr}]^T$ is Nr-dimension additive white Gaussian noise (AWGN) vector and $(\cdot)^T$ is the transpose of the vector [2, 5]. The detection of information bits can be achieved by estimating the antenna number then estimate the transmitted symbol according to equation(1) [3, 5]:

$$\hat{j} = \arg_j \max \left| h_j^H y \right| \text{ and } \hat{q} = \arg_q \max \operatorname{Re} \left| (H_{\hat{j} x_q})^H y \right| \quad (1)$$

where $\hat{j}$ and $\hat{q}$ are the estimated antenna number and transmitted symbol, respectively. The original information bits can be retrieved when the two estimate are both correct.

3 Performance Analyses

L independent but not necessarily identical Weibull fading channels are considered. The instantaneous SNR at the output of the L-branch combiner is:

$$\gamma_{MRC} = \sum_{i=1}^{L} \gamma_i \quad (2)$$

where γ_i is the instantaneous SNR of the ith diversity branch.

The probability density function (PDF) of the instantaneous received SNR, denoted γ_i, under the Weibull fading model is given in [9] as:

$$p_\gamma(\gamma_i) = \frac{\beta}{2}\left[\frac{\Gamma\left(1+\frac{2}{\beta}\right)}{\bar{\gamma}}\right]^{\frac{\beta}{2}} \gamma_i^{\frac{\beta}{2}-1} \exp\left[-\left(\frac{\gamma_i}{\bar{\gamma}}\Gamma\left(1+\frac{2}{\beta}\right)\right)^{\frac{\beta}{2}}\right]$$

(3)

where β is the Weibull fading severity parameter (β > 0). As the value of β increases, the severity of the fading decreases. For the special case of β=4, (3) reduces to the well-known Rayleigh pdf, $\bar{\gamma}$ is the average fading power and Γ(.) denotes the gamma function.

The moment generating function (MGF) of γ maximum ratio combining (MRC) is defined as $\mu_{\gamma MRC}(s) = E(e^{-s\gamma_{MRC}})$ with E(.) represents the mathematical expectation operator. The MGF can be expressed as [9]:

$$\mu_{\gamma MRC}(s) = \frac{\beta\left(\Gamma\left(1+\frac{2}{\beta}\right)\right)^{\frac{\beta}{2}}}{2(\bar{\gamma}_1)^{\frac{\beta}{2}}} \frac{\left(\frac{k}{l}\right)^{\frac{1}{2}}\left(\frac{l}{s}\right)^{\frac{\beta}{2}}}{(2\pi)^{\frac{k+l}{2}-1}} \prod_{i=1}^{L} G_{l,k}^{k,l}\left[\frac{\left(\frac{\bar{\gamma}_1}{\Gamma\left(1+\frac{2}{\beta}\right)}\right)^{\frac{-k\beta}{2}}}{s^l}\frac{l^l}{k^k}\left| \begin{matrix} I\left(l, 1-\frac{\beta}{2}\right) \\ I(k,0) \end{matrix}\right.\right] \quad (4)$$

where k and l are the minimum integers chosen such that β/2=l/k, $I(n,\zeta) = \frac{\zeta}{n}, \frac{\zeta+1}{n}, \dots, \frac{\zeta+n-1}{n}$ and $G_{p,q}^{m,n}(.)$ is the Meijer G-function.

The probability of symbol error for M-QAM signals over generalized fading channels can be expressed as in [10]:

$$P_{s,M-QAM}(e) = \frac{4B}{\pi}\int_0^{\frac{\pi}{2}} \mu_{\gamma MRC}\left(-\frac{g}{\sin^2\theta}\right) d\theta - \frac{4B^2}{\pi}\int_0^{\frac{\pi}{4}} \mu_{\gamma MRC}\left(-\frac{g}{\sin^2\theta}\right) d\theta \quad (5)$$

where $g_{M-QAM} = \frac{3}{2(M-1)}$ and $B = 1 - \frac{1}{\sqrt{M}}$

The error performance of M-QAM in conjunction with MRC diversity can be easily evaluated via numerical integration, since (5) consists of single integrals with finite limits and integrands composed of functions which behave quite well in the range of the integrals' limits.

The integration method illustrated in [11] is deployed in this work due to its more accuracy compared to the Order Statistics (OS) method over the range from 0dB to 18dB and it has quite similar performance for higher SNR range [11].

As described earlier, the transmit antenna number estimation problem can be summarized as choosing the index corresponding to the maximum absolute value of the vector **g = HHy**, whose elements follow complex Gaussian distributions. The absolute value of each element of the received vector g is then distributed according to χ-distribution (pdf) with two degrees of freedom and a noncentrality parameter δ which is related to the normalized squared mean values of both real and imaginary components of g.

Let us consider N_t transmit antennas. Based on the decision rule in (1), the average probability of incorrect detection of the transmit antenna number namely k (Pa), can be explicitly written as follows [11]:

$$P_a = \frac{1}{b.\frac{Nt}{2}} \sum_{k,P_x} \omega_x\left(1 - P_c(k, P_x)\right) \quad (6)$$

where $P_c(k, P_x)$ is defined as follows [11]:

$$P_c(k, P_x) = \int_0^\infty f_k(y) \prod_{i=1, i\neq k}^{N_t} F_i(y) dy \quad (7)$$

where Px is the power of x, b is the number of symbols in one quadrant of the modulation alphabet and ωx be a weight factor, corresponding to the number of times the power rating Px occurs in one quadrant of the constellation diagram.

The results in (5) and (6) can be deployed in (8) to obtain the overall symbol error probability of SM [2].

$$P_e = P_s + P_a - P_s P_a \tag{8}$$

4 Results

This section presents the calculated and simulated (using Monte Carlo simulations) average SER for spatial modulation systems over Weibull fading channel. Two modulation schemes namely, 16-QAM and 64-QAM and different Nt×Nr schemes are considered.

Figures 2 and 3 show the analytical and simulated SER performance of SM; 16 QAM 4x4 and 64QAM 4x4, respectively. Investigating the two figures, it is clear that the analytical and the simulation results are in close agreements. Also, it is clear that as the fading parameter decreases, i.e. fading severity increases, the performance degrades.

In figures 4 and 5, the effect of increasing the number of receiving antenna (N_r) for 16-QAM and 64-QAM spatial modulation under uncorrelated weibull fading is illustrated, respectively. Diversity gain can be noticed; the performance improves significantly as the number of diversity branches (Nr) increases. β=2 is selected to model a severe fading channel.

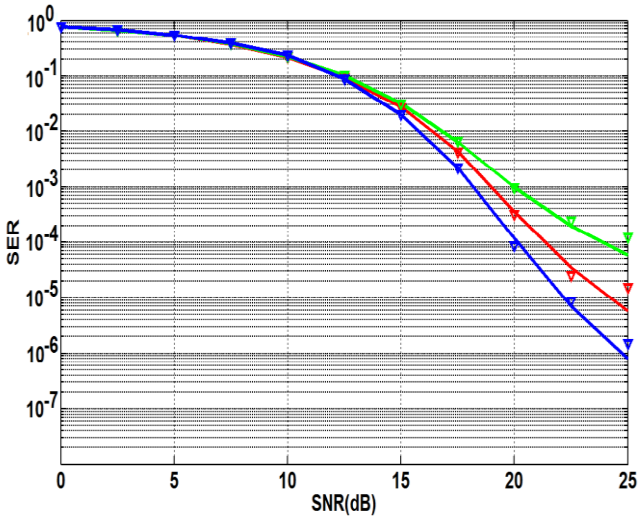

Figure 2. SER performance of 4×4 16-QAM spatial modulation under Weibull fading channel for β=2 (green), β=4 (red),and β=6 (blue) : analytical (lines) and simulation (markers).

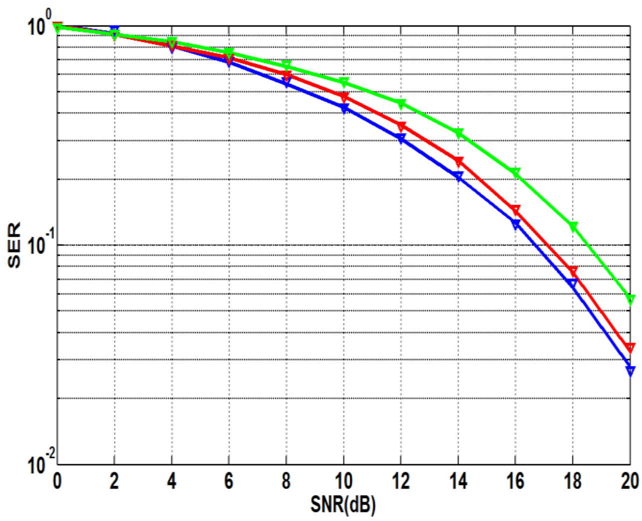

Figure 3. SER performance of 4×4 64-QAM spatial modulation under Weibull fading channel for β=2 (green), β=4 (red), and β=6 (blue) : analytical (lines) and simulation (markers).

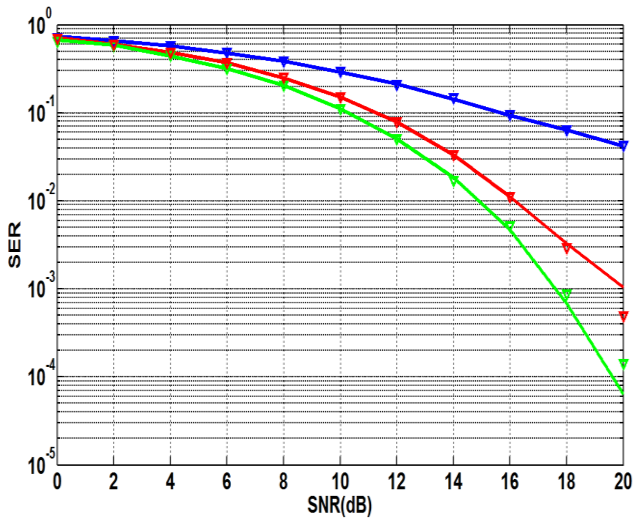

Figure 4. SER performance of 16-QAM spatial modulation under Weibull fading channel for β=2 with various SM schemes including 4×2 (blue), 4×4 (red), and 4×8 (green): analytical (lines) and simulation (markers).

5 Conclusions

Closed-form integral expressions for the average SER of SM in Weibull fading channels were derived. Extensive computer simulations were carried out. Both simulation and analytical results are in excellent agreement, which validates the mathematical analysis.

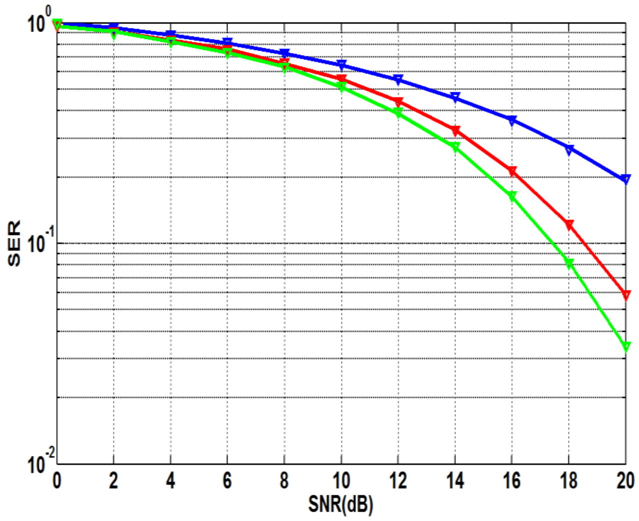

Figure 5. SER performance of 64-QAM spatial modulation under Weibull fading channel for β=2 with various SM schemes including 4×2 (blue), 4×4 (red), and 4×8 (green): analytical (lines) and simulation (markers).

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