Performance of Downlink CDMA-SFBC Over Weibull Fading Channels

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***Abstract*—In this paper, we consider code division multiple access (CDMA) - space frequency block coded (SFBC) downlink system and evaluate its performance over independent and identically distributed (i.i.d) Weibull fading channels. Specifically, we drive closed form bit error rate (BER) expressions for the M-ary quadrature amplitude modulation (MQAM) and M-ary phase shift keying (MPSK). We study the outage probability of the system by numerically inverting the Laplace transform of the cumulative distribution function of the instantaneous signal to noise ratio. The derived expressions are evaluated considering different amounts of channel estimation error, different M-ary size, different fading severities and different SFBC forms. Numerical results are provided to show the tradeoff between the different system parameters. The derived expressions can be used to assign channels to different users in a cross-layered fashion based on the conditions of their channels.**

***Index Terms*—Code division multiple access (CDMA), Space frequency block code (SFBC), Orthogonal frequency division multiplexing (OFDM), Multiple input multiple output (MIMO), Weibull fading channel, BER, Estimation error.**

I. Introduction

Wireless communication links equipped with multiple antennas at both transmitter and receiver known as (MIMO) systems are gaining popularity in the next generation wireless networks. MIMO systems can be used to increase the diversity gain of the link to overcome the fading nature of the wireless channel or can be used to increase the bit rate of the system through spatial multiplexing. Therefore, MIMO systems have been adapted in many communication systems such as WiMAX, IEEE802.11n and 3GPP long term evolution.

Moreover, space time block codes (STBC) are used to get maximum diversity gain. Several STBCs have been designed [1]–[3] in order to get maximum diversity gain in MIMO systems. The use of orthogonal STBCs allows low complexity maximum likelihood (ML) decoding. Orthogonal frequency division multiplexing (OFDM) technique is used to divide the frequency selective fading channel into multiple flat fading sub-channels. It is also used to mitigate the effects of ISI [4], and to support variable rates for different users. The advantages of OFDM and STBC can be combined together in what is known as space frequency block coding (SFBC). OFDM can be also combined with code division multiple access (CDMA) producing what is called multi-tone (MT)-CDMA [5]. In MT-CDMA spreading is done in the time domain using spreading codes with lengths larger than the number of OFDM tones and hence the system can serve larger number of users compared to direct sequence (DS)-CDMA [5]. In the literature, there are several schemes that combine MIMO with OFDM, STBCs, and CDMA. In [6], J. young et al. proposed an adaptive constrained minimum mean square error (CMMSE) receiver for single carrier STBC-CDMA systems. In [7], Vook et al. proposed a cyclic prefix single carrier CDMA system with antenna diversity at both the transmitter and the receiver. In [8], Auffray and Helard studied the performance of multi-carrier (MC)-CDMA combined with STBC over Rayleigh fading channel for one or two transmit antennas. In [9], Torabi et al. derived closed form expressions for the bit error rate (BER) of SFBC-OFDM system over Rayleigh fading channels. In [10], Aldalgamouni *et. al*. proposed and studied the BER performance of CDMA-SFBC downlink system over Rayleigh fading channel.

Manuscript received February 21, 2012; revised March 25, 2012.

Most of the previous works in the literature studied the BER performance over Rayleigh fading channels. Digital communications over Weibull fading channels has recently received the interest of several researchers (see, for example [11]–[15]). It was found in [16]–[19] that the Weibull distribution has the flexibility to fit experimental fading channel measurements for both indoor and outdoor environments. The Weibull and the Nakagami-m models have been recommended by the IEEE Vehicular technology society committee on radio propagation to theoretically study slope changes in the tail of the model distribution to compensate for some of the weaknesses of the Rayleigh distribution [18].

Several numerical methods have been suggested to compute the outage probability of orthogonal STBC systems over generalized fading channels. In [20], Alouini et al. evaluated the outage probability of diversity systems with maximal-ratio combining (MRC) over generalized fading channels using a moment generating function-based technique. Their approach is based on numerical inversion of Laplace transform which was originally presented in [21]. In [22], the authors introduced a general and simple Fixed-Talbot algorithm to numerically invert the laplace transform.

In this paper, we adapt the downlink CDMA-SFBC system which was proposed in [10] to combine the advantages of MIMO, STBC, OFDM and CDMA systems in one system.

The adapted CDMA-SFBC system exploits time, space, code, and frequency diversities of the channel which will

doi:10.4304/jcm.7.4.321-328

greatly improve reception. We analyze the performance of the system assuming independent and identically distributed (i.i.d) Weibull fading channels. We derive and evaluate closed form expressions for the BER of the system considering M-ary quadrature amplitude modulation (MQAM) and M-ary phase shift keying (MPSK) modulation techniques. These expressions show the effects of channel estimation errors, fading severity, number of transmit and receive antennas and the alphabet size of the modulation scheme on the BER performance. In our analysis, we assume the effects of frequency selectivity in fading channels are neglected; this assumption is acceptable when the cyclic prefix is larger than the delay spread of the channel and the spreading codes resolve the frequency selective channels [23]. The derived expressions can be used to assign channels to different users in a cross-layer fashion. Moreover, we study the outage probability performance of the system by numerically inverting the Laplace transform of the cumulative distribution function (CDF) of the instantaneous signal to noise ratio (SNR) using the simple and accurate algorithm presented in [21]. The reminder of this paper is organized as follows: the system model is shown and explained in Section II. BER performance for MQAM and MPSK downlink CDMA-SFBC systems over Weibull fading channel are studied in Sections III and IV respectively. Performance over Rayleigh fading channel is illustrated in Section V. Outage probability is presented in Section VI. Numerical results are provided in Section VII while concluding remarks are drawn in Section VIII.

II. System Model

The system model considered in this paper is illustrated in Figure 1. It shows a downlink system, i.e. from the base station to the mobile station, for one user only with M_T transmit and M_R receive antennas. At the transmitter side, the data bits are first converted from serial to parallel and then modulated using MQAM/MPSK modulator where $M = 2^b$ and b is the number of allocated bits per symbol to generate a signal vector S.
The generated vector S includes $L \times R_c$ information symbols where L is equal to the total number of available OFDM tones and R_c is the rate of the STBC code.
The signal vector S is then provided as an input to the STBC encoder. The STBC encoder is defined by its $q \times M_T$ generating matrix. The STBC encoder generates M_T blocks, $S_1 \dots S_{M_T}$. Each one of these blocks has a length of L and consists of F sub-blocks, such that $F = L/q$ and each sub-block has a length of q. Then, using inverse fast Fourier transform (IFFT), OFDM modulation is performed on $S_1 \dots S_{M_T}$. This process generates blocks $X_1 \dots X_{M_T}$ which will be assigned a Walsh orthogonal function w_1 then transmitted by its corresponding antenna.
For Alamouti's scheme with two transmit antennas [1], we will have $S = [s(0)\, s(1) \dots s(L-1)]^T$, $S_1 = [s(2K) - s^*(2K+1)]^T$ and $S_2 = [s(2K+1)\, s^*(2K)]^T$ where $0 \le K \le F-1$. The $(\ .)^*$ and $(\ .)^T$ denote the complex conjugate and the vector transpose operators respectively. OFDM tones are assigned to symbols such that the first symbol transmitted from each antenna is transmitted on the first tone, the second symbol transmitted from each antenna is transmitted on the second tone and so on. See Table 1.

TABLE I
Frequency Mapping

Subcarrier	Antenna 1	Antenna 2
$2K$	$s(2K)$	$s(2K+1)$
$2K+1$	$-s^*(2K+1)$	$s^*(2K)$

The slow variation of the fading channel in usual indoor environments allows us to assume the channel to be a quasi-static Weibull fading channel (i.e. the channel remains fixed for the duration of one OFDM block).

The envelope of Weibull fading channel has the following probability density function (pdf), [24]:

$$f_X(x) = \frac{\beta x^{\beta-1}}{\Omega} exp\ [\frac{-x^{\beta}}{\Omega}], x \ge 0 \tag{1}$$

where β represents the fading parameter and Ω is the mean of x^β (i.e. $E[x^\beta]$). At the receiver, the signal will be multiplied by its corresponding Walsh function, and then filtered by a low pass filter (LPF). OFDM demodulation is done using fast Fourier transformation (FFT).The STBC decoder utilizes the channel state information (CSI) to decode the received signal and generate an estimate of the transmitted signal ($\tilde{S}$) using ML detection. Following that, the signal will be demodulated by the MQAM/MPSK demodulator and converted into serial format.

III. BER PERFORNACE OF THE DOWNLINK CDMA-SFBC MQAM SYSTEM OVER WEIBULL FADING CHANNEL

Assuming MQAM modulation with Gray coding and $M = 2^b$, the instantaneous BER of the K^{th} sub-channel can be expressed as in [25]:

$$BER_{MQAM}[qK] = 2\frac{\left(1-\frac{1}{\sqrt{2^b}}\right)}{b}\text{erfc}\left(\sqrt{\frac{1.5\gamma[qK]}{2^b-1}}\right) \tag{2}$$

Where erfc(x) is the complementary error function i.e. erfc$(x) = \int_x^\infty e^{-t^2}dt$. $\gamma[qK]$ is the instantaneous SNR derived in [10] as

$$\gamma[qK] = \frac{\gamma_s \sum_{i=1}^{M_T}\sum_{j=1}^{M_R}|H_{i.j}[qK]|^2}{R_c M_T(\gamma_s\sigma_e^2+1)} \tag{3}$$

Where $H_{i.j}(qK)$ is the discrete Fourier transform (DFT) of the Weibull channel coefficient between the i^{th} transmit and the j^{th} receive antennas of the intended user, which is assumed to be the first user.

$$\gamma_s = \frac{P_s}{\sigma_n^2}$$

Where P_s is the symbol power at the transmitter and σ_n^2 is the variance of the additive white Gaussian noise (AWGN). $\sigma_e^2$is the variance of channel estimation error. Interested readers are referred to [10] for detailed information.

In this paper and considering the K^{th} sub-channel, we use the approximate expression which is given by [26] and [27]:

$$BER_{MQAM}\left[qK\right] = 0.2\exp\left(\frac{-1.6\gamma\left[qK\right]}{2^b-1}\right) \quad (4)$$

Now, the average BER can be obtained by integrating over the pdf of the output SNR denoted by γ as follows:

$$\overline{BER}_{\mathrm{MQAM}} = \frac{1}{L}\sum_{K=0}^{L-1}\int_0^{\infty}\ldots\int_0^{\infty} BER_{MQAM}\left[qK\right] \times P\left(\gamma_{1,1}\right)\ldots P\left(\gamma_{M_T,M_R}\right) d\gamma_{1,1}\ldots d\gamma_{M_T,M_R} \quad (5)$$

Where $\gamma_{i,j}$ is the instantaneous SNR for the channel link between the i^{th} transmit and the j^{th} receive antennas.

$$\gamma_{i,j}\left[qK\right] = \frac{\gamma_s\left|H_{i,j}\left[qK\right]\right|^2}{M_T R_c\left(\gamma_s\sigma_e^2+1\right)} \quad (6)$$

Since $\left|H_{i,j}\left[qK\right]\right|$ is Weibull distributed with parameters $(\beta,\ \Omega)$ then, $\left|H_{i,j}(qK)\right|^2$ is also a Weibull distributed random variable with parameters $(\beta/2,\Omega)$. Therefore $\gamma_{i,j}$ is also Weibull distributed with parameters $\left(\beta/2,(\alpha\overline{\gamma_{i,j}})^{\frac{\beta}{2}}\right)$. i.e.

$$P\left(\gamma_{i.j}\right) = \frac{\beta/2}{\left(\alpha\overline{\gamma}_{i.j}\right)^{\frac{\beta}{2}}}{\gamma_{i.j}}^{\beta/2-1}\exp\left[-\left(\frac{\gamma_{i.j}}{\alpha\overline{\gamma}_{i.j}}\right)^{\frac{\beta}{2}}\right]\ \gamma\geq 0 \quad (7)$$

where $\alpha = \frac{1}{\Gamma\left(1+\frac{2}{\beta}\right)}$, and $\overline{\gamma}_{i.j}$ is the average SNR given by

$$\overline{\gamma}_{i.j} = \frac{\gamma_s}{M_T R_c\left(\gamma_s\sigma_e^2+1\right)}\Omega^{\frac{2}{\beta}}\Gamma\left(\frac{2}{\beta}+1\right) \quad (8)$$

Substituting (8) into (7) and (3) into (4) and then using the results in (5) yields:

$$\overline{BER}_{\mathrm{MQAM}}=\frac{1}{L}\sum_{K=0}^{L-1}\int_0^{\infty}\ldots\int_0^{\infty}.2\exp\left(\frac{-1.6\gamma}{2^b-1}\right)\times \frac{\beta/2}{\left(\alpha\overline{\gamma}_{1,1}\right)^{\frac{\beta}{2}}}{\gamma_{1,1}}^{\beta/2-1}exp\left[-\left(\frac{\gamma_{1,1}}{\alpha\overline{\gamma}_{1,1}}\right)^{\frac{\beta}{2}}\right]\ldots \times \frac{\beta/2}{\left(\alpha\overline{\gamma}_{M_T,M_R}\right)^{\frac{\beta}{2}}}{\gamma_{M_T,M_R}}^{\beta/2-1}\times exp\left[-\left(\frac{\gamma_{M_T,M_R}}{\alpha\overline{\gamma}_{M_T,M_R}}\right)^{\frac{\beta}{2}}\right] \times d\gamma_{1,1}\ldots d\gamma_{M_T,M_R} \quad (9)$$

Assuming i.i.d Weibull fading channels then, $\overline{\gamma}_{i,j}$ for all i,j are equal, and we let $\overline{\gamma}_{i,j}=\overline{\gamma}$. Note that each term in the summation in (9) is not a function of K. Then using the result in [28, eq. 2.24.1.1], we can write the average BER expression as follows:

$$\overline{BER}_{MQAM} = 0.2\left(\frac{l^{l/k+\frac{1}{2}}}{\sqrt{k}(2\pi)^{(l+k-2)/2}\left(\frac{1.6\alpha\overline{\gamma}}{(2^b-1)}\right)^{l/k}}\right)^{M_TM_R} \times\left[G_{l,k}^{k,l}\left(\frac{l^l}{(\alpha\overline{\gamma})^l\left(\frac{1.6}{(2^b-1)}\right)^l k^k}\middle|\begin{array}{c}\Delta\left(l,1-\frac{l}{k}\right)\\ \Delta\left(k,0\right)\end{array}\right)\right]^{M_TM_R} \quad (10)$$

where $G_{m,n}^{p,q}\left(x\middle|\begin{array}{c}a_i\\ b_i\end{array}\right)$ is the Meijer's G-function defined in [29], and we used $\frac{\beta}{2}=\frac{l}{k}$ such that $gcd(l,k)=1$ and $\Delta(n,\xi)=\xi/n,(\xi+1)/n,...,(\xi+n-1)/n$.

IV. BER PERFORMNACE OF THE DOWNLINK CDMA-SFBC MPSK SYSTEM OVER WEIBULL FADING CHANNEL.

In this section, we use the exponential approximation of the BER of MPSK given in [26]:

$$BER_{MPSK}\left[qK\right] = 0.2\exp\left(\frac{-7\gamma\left[qK\right]}{2^{1.9b}+1}\right) \quad (11)$$

Following the same steps as in the previous section, the average BER of MPSK is obtained as follows:

$$\overline{BER}_{MPSK} = 0.2\left(\frac{l^{(l/k+0.5)}\left(\alpha\overline{\gamma}\right)^{-l/k}}{\sqrt{k}(2\pi)^{\frac{l}{2k}-1}\left(\frac{7}{(2^{1.9b}+1)}\right)^{l/k}}\right)^{M_TM_R} \times\left[G_{l,k}^{k,l}\left(\frac{l^l}{(\alpha\overline{\gamma})^{\frac{l}{2}}\left(\frac{7}{(2^{1.9b}+1)}\right)^l k^k}\middle|\begin{array}{c}\Delta\left(l,1-l/k\right)\\ \Delta\left(k,0\right)\end{array}\right)\right]^{M_TM_R} \quad (12)$$

V. PERFORMANCE OVER RAYLEIGH FADING CHANNEL

The performance of SFBC-CDMA over Rayleigh fading channel can be obtained from the expressions derived in Section III and Section IV as a special case by letting the fading parameter equal to two (i.e. β=2) , as follows: For the MQAM system (10) can be simplified to:

$$\overline{BER}_{MQAM}=0.2\left(\frac{2^b-1}{1.6\alpha\overline{\gamma}}G_{1,1}^{1,1}\left(\frac{2^b-1}{1.6\alpha\overline{\gamma}}\middle|\begin{array}{c}0\\ 0\end{array}\right)\right)^{M_TM_R} \quad (13)$$

also, (12) can be simplified to

$$\overline{BER}_{MPSK}= 0.2\left(\frac{2^{1.9b}+1}{7\alpha\overline{\gamma}}G_{1,1}^{1,1}\left(\frac{2^{1.9b}+1}{7\alpha\overline{\gamma}}\middle|\begin{array}{c}0\\ 0\end{array}\right)\right)^{M_TM_R} \quad (14)$$

From [29]

$$(1+x)^{-e} = \frac{1}{\Gamma(e)}G_{1,1}^{1,1}\left(x\middle|\begin{array}{c}1-e\\ 0\end{array}\right) \quad (15)$$

Using (15) and substituting for $\overline{\gamma}$ by (8) yields,

$$\overline{BER}_{MQAM} = 0.2\left(1+\frac{1.6\gamma_s}{M_T R_c\left(2^b-1\right)\left(\gamma_s\sigma_e^2+1\right)}\right)^{-M_TM_R} \quad (16)$$

and for MPSK

$$\overline{BER}_{MPSK} = 0.2\left(1+\frac{7\gamma_s}{M_T R_c\left(2^{1.9b}+1\right)\left(\gamma_s\sigma_e^2+1\right)}\right)^{-M_TM_R} \quad (17)$$

Which are the same expressions derived in [10].

VI. OUTAGE PROBABILITY EVALUATION

Outage probability is an important performance criterion of wireless communication systems. It is defined as the probability that the instantaneous SNR falls below a certain predefined threshold, i.e.

$$P_{out} = P\left[0 \leq \gamma \leq \gamma_{th}\right] = \int_0^{\gamma_{th}} p(\gamma)\, d\gamma \qquad (18)$$

The authors in [20] evaluated the outage probability of diversity systems over generalized fading channels by numerically inverting the Laplace transform of the CDF of the instantaneous SNR. Their approach was based on the numerical inversion technique of the Laplace transform developed in [21].

Following their work, P_{out} can be evaluated using

$$\begin{aligned} P_{out} &= \\ & 2^{-Q}\frac{e^{\frac{A}{2}}}{\gamma_{th}}\sum_{q=0}^{Q}\binom{Q}{q}\sum_{n=0}^{N+q}\frac{(-1)^n}{\zeta_n}\Re\left[\frac{\Phi_t\left(-\frac{A+2\pi ni}{2\gamma_{th}}\right)}{\frac{A+2\pi ni}{2\gamma_{th}}}\right] \\ + \quad & E(A,Q,N) \qquad (19) \end{aligned}$$

$$\zeta_n = \begin{cases} 2 & n=0 \\ 1 & n=1,2,\cdots,N \end{cases}$$

$\Re[.]$ denotes the real part of a complex argument, $E(A,Q,N)$ corresponds to the overall discretization and series truncation error terms and it is approximately bounded by

$$|E(A,Q,N)| \simeq \frac{e^{-A}}{1-e^{-A}} + \left|2^{-Q}\frac{e^{A/2}}{\gamma_{th}}\right| \times$$

$$\left|\sum_{q=0}^{Q} -1^{(N+1+q)}\binom{Q}{q}\Re\left[\frac{\Phi_t\left(-\frac{A+2\pi i(N+q+1)}{2\gamma_{th}}\right)}{\frac{A+2\pi i(N+q+1)}{2\gamma_{th}}}\right]\right| \qquad (20)$$

The constants A, N and Q are selected to achieve a certain predefined accuracy. This approach applied the Euler summation technique to accelerate the alternating series convergence. $\Phi(s)$ is the MGF of the SNR of the given distribution.

In [22] a new Fixed-Tablot based algorithm has been proposed to numerically invert the Laplace transform in a simpler and more efficient way. These approaches can be applied to Weibull fading channel.

Remember here that $\gamma_{i,j}$ is the instantaneous SNR for the channel link between the i^{th} transmit and the j^{th} receive antennas and it is given by (6). Again assuming i.i.d Weibull fading channels then, $\overline{\gamma}_{i,j}$ for all i, j are equal, and $\overline{\gamma}_{i,j} = \overline{\gamma}$ where $\overline{\gamma}_{i.j}$is the average SNR given by (8). For uncorrelated fading, the MGF of the total SNR is the product of the MGFs of each individual branch SNR,

$$\Phi_t(s) = \prod_{i,j=1}^{M_T M_R} \Phi_{\gamma_{i,j}}(s) \qquad (21)$$

Where $\Phi_t(s)$ is the MGF of the total SNR.

$\Phi_{\gamma_{i,j}}(s)$ is the MGF of the SNR between the i^{th} transmit and the j^{th} receive antennas.

Following the assumption of uncorrelated fading,

$$\Phi_t(s) = \left(\Phi_\gamma(s)\right)^{M_T M_R} \qquad (22)$$

$$\Phi_\gamma(s) = \int_0^\infty e^{-\gamma s} p(\gamma)\, d\gamma \qquad (23)$$

By substituting for $p(\gamma)$ in (23) yields

$$\Phi_\gamma(s) \quad = \frac{\beta/2}{(\alpha\overline{\gamma})^{\frac{\beta}{2}}}\int_0^\infty \gamma^{\beta/2-1} e^{-\gamma s} exp\left[-\left(\frac{\gamma}{\alpha\overline{\gamma}}\right)^{\frac{\beta}{2}}\right] d\gamma \qquad (24)$$

By expressing the exponential function as a Meijer's G-function [30, (8.4.3.1)]:

$$\exp(-\alpha x^c) = G_{10}^{01}\left(\alpha x^c \,\middle|\, \begin{matrix} - \\ 0 \end{matrix}\right) \qquad (25)$$

equation (24) becomes:

$$\Phi_\gamma(s) = \frac{\beta/2}{(\alpha\overline{\gamma})^{\frac{\beta}{2}}}\int_0^\infty \gamma^{\beta/2-1} e^{-\gamma s} G_{10}^{01}\left(\left(\frac{\gamma}{\alpha\overline{\gamma}}\right)^{\frac{\beta}{2}} \,\middle|\, \begin{matrix} - \\ 0 \end{matrix}\right) d\gamma \qquad (26)$$

Then using the integral in [28, (2.24.1.1)] yields to:

$$\begin{aligned} \Phi_\gamma(s) \quad &= \frac{\frac{l}{k}}{(a\overline{\gamma})^{\frac{l}{k}}} \times \frac{\sqrt{k}\, l^{l/k-\frac{1}{2}}}{(2\pi)^{\frac{l+k-2}{2}} s^{\frac{l}{k}}} \\ &\times G_{lk}^{kl}\left(\frac{l^l}{(a\overline{\gamma})^l s^l k^k} \,\middle|\, \begin{matrix} \Delta(l, 1-l/k) \\ \Delta(k, 0) \end{matrix}\right) \qquad (27) \end{aligned}$$

Where

$$\alpha = \frac{1}{\Gamma\left(1+\frac{2}{\beta}\right)}, \quad \overline{\gamma} = \frac{\gamma_s}{M_T(\gamma_s\sigma_e^2+1)}\Omega^{\frac{2}{\beta}}\Gamma\left(\frac{2}{\beta}+1\right) \qquad (28)$$

Hence, substituting (27), in (22) yields:

$$\begin{aligned} \Phi_t(s) \quad &= \left(\frac{\frac{l}{k}}{(a\overline{\gamma})^{\frac{l}{k}}} \times \frac{\sqrt{k}\, l^{l/k-\frac{1}{2}}}{(2\pi)^{\frac{l+k-2}{2}} s^{\frac{l}{k}}}\right)^{M_T M_R} \\ \times \quad & \left(G_{lk}^{kl}\left(\frac{l^l}{(a\overline{\gamma})^l s^l k^k} \,\middle|\, \begin{matrix} \triangle(l, 1-l/k) \\ \triangle(k, 0) \end{matrix}\right)\right)^{M_T M_R} \qquad (29) \end{aligned}$$

Substituting (29) in (19) and (20), the outage probability can be computed using some mathematical packages such as Maple.

VII. NUMERICAL RESULTS

In this section, we evaluate the derived BER and outage probability expressions for the downlink CDMA-SFBC system over a wide range of system parameters. These parameters include channel estimation error variance, alphabet size, number of transmit and receive antennas, and fading severity.

In Fig. 2, we provide the BER performance for the downlink CDMA-SFBC system over Weibull multipath fading for different coherent modulation techniques with different number of antennas considering $\beta = 2$, which corresponds to the Rayleigh channel model, showing a good match with the previously obtained results for Rayleigh in Fig.3 [10].

In Fig.3, the BER performance for QPSK modulation technique with dual antenna reception ($M_R = 2$) is evaluated for different values of the fading parameter with estimation error variance of 0.01. As expected, as the value of the fading parameter increases, which means less fading, the performance of the system will improve. For instance, when β increases from 2 to 6 at $\overline{\gamma}$= 30 dB the BER goes down from approximately $1 \times 10^{-4}$to 1×10^{-9} which is a great improvement. Fig.4 provides the BER performance curves versus the average SNR for different values of the fading parameter, estimation error, and antennas configurations. Note that controlling the antenna configurations and estimation errors for given channel severity conditions can significantly compensate for the BER degradation caused by the multipath fading. For instance, for the 4T×2R communication system, the BER degradation caused by the use of Rayleigh fading channel ($\beta = 2$) can be compensated for by raising the diversity order of the system.

Fig.5 shows the BER performance of QPSK versus channel estimation error variance for different antenna configurations, different amounts of fading, and different average SNR.

Fig.6 shows the BER versus the alphabet size for different values of fading parameters. It is well shown that there is degradation in the system performance by increasing the modulation order, we can compensate for this degradation by increasing the diversity order.

In the subsequent figures, we consider the MQAM modulation technique. For instance, Fig.7 shows the BER of MQAM for different modulation orders demonstrating the effect of increasing the M-ary size for a CDMA-SFBC downlink system with 2×2 antenna configuration at a given fading parameter and estimation error. It is clearly observed that increasing the modulation order will degrade the BER performance as expected. On the other hand, the effect of the channel estimation error σ_e^2 is described in Fig.8 showing that the BER performance curves would be negatively affected by increasing σ_e^2 since the STBC decoder requires accurate CSI to decode the received signal. It is noteworthy mentioning that the obtained curves in Fig.7 and Fig.8 match exactly the curves previously published for the Rayleigh case in the literature since $\beta = 2$ corresponds to Rayleigh fading [10].
In Fig.9, the BER performance curves of the 2×2 4-QAM modulation technique are presented for different values of the fading parameter β and for σ_e^2= 0.01. In general, as the fading parameter β increases the performance of the system improves since the amount of fading decreases. The previously obtained results indicate that the derived BER expression can be used in adaptive modulation algorithms. For instance, if the severity level of the fading channel increases, then the modulation order needs to be adaptively decreased and the estimation of the channel state information necessitates to be more accurate. On the other hand, if we have less fading then more bits can be transmitted, i.e., larger modulation order, and the estimation of the channel state information can be more flexible, and hence simpler structure can be implemented at the receiver side.

The outage probability versus the normalized average SNR of CDMA-SFBC systems is presented in Fig. 10, considering different fading parameters, namely; $\beta = 4$ and $\beta = 2$ (Rayleigh case). These curves were generated using the MGF-based approach developed in [20] which relies on the Euler summation-based algorithm for the Laplace inversion of CDFs

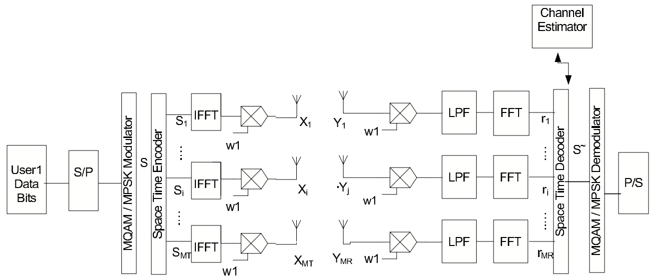

Fig. 1. CDMA-SFBC Downlink System Model.

[21], with A set to $10 \ln 10 \simeq 23.026$ to generate a dicretization error less than 10^{-10}, which is negligible amount as compared to the outage probability. The parameters N and Q were set to 15 and 11 respectively. The provided numerical curves indicate that the outage probability significantly improves when the fading parameter increases. For instance, the curves for $\beta = 4$ case is sharper than those for $\beta = 2$. In addition to that, it is well-known that the outage performance improves as the diversity order increases.

Finally, Fig.11 demonstrates the outage performance versus the average SNR with different system configurations (different number of antennas at both sides) showing the effect of channel estimation error σ_e^2, and fading parameter on the performance curves.

VIII. CONCLUSION

In this paper, we considered CDMA-SFBC system in the downlink transmission and we evaluated the BER and the outage probability performance metrics considering the Weibull multipath fading channel.
Closed-form expressions for the BER considering coherent MQAM and MPSK modulation techniques were also derived. The expressions were evaluated for a wide range of the average SNR, channel estimation error variance, modulation alphabet size, and different values of the Weibull fading parameter. The outage probability was also evaluated using the MGF-based approach which was developed in [20] and relying on the so-called Euler summation-based algorithm for the inversion of CDFs [21]. It was shown numerically that the performance of the system is improved as the fading parameter increases, while a noticeable degradation was observed with increasing the channel estimation error variance and the size of modulation alphabet. We believe that the obtained expressions along with the obtained curves could be helpful for researchers interested in this area.

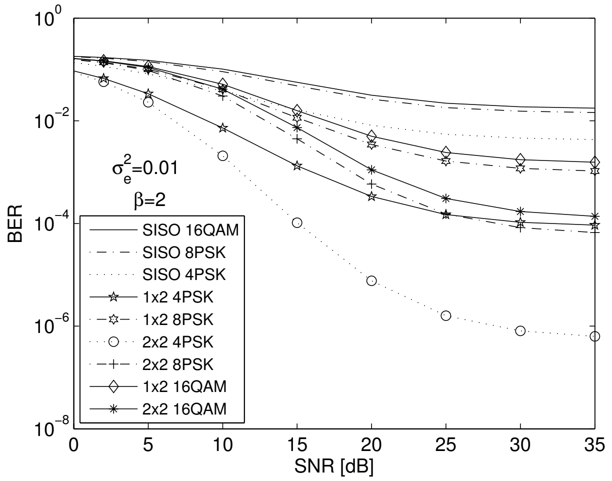

Fig. 2. BER versus SNR showing the effect of different modulation technique on different downlink systems over Weibull fading channel with $\beta = 2$ and $\sigma_e^2 = 0.01$.

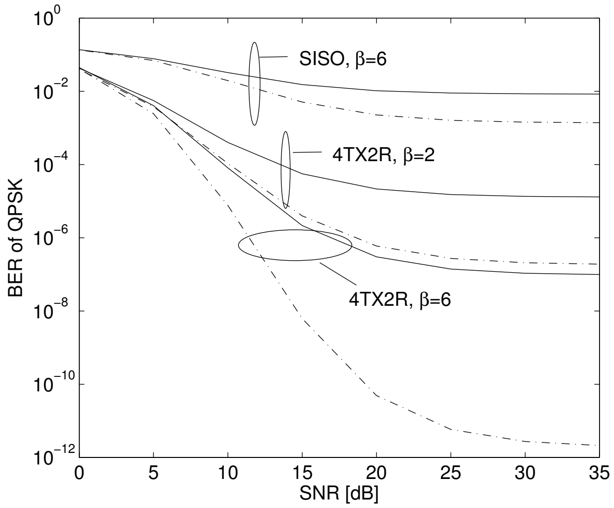

Fig. 4. The performance of BER of QPSK system versus SNR including the effect of channel estimation error over Weibull fading channel for $\beta = 2$, and $\beta = 6$.

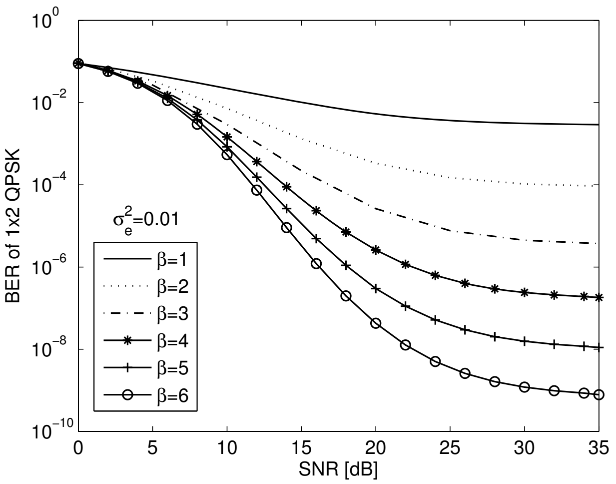

Fig. 3. BER performance of $1X2$ QPSK downlink CDMA-SFBC system versus SNR showing the effect of increasing β with $\sigma_e^2 = 0.01$.

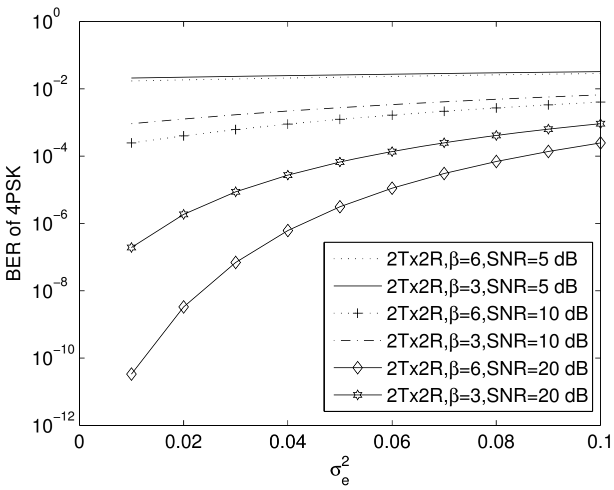

Fig. 5. BER performance for 4PSK versus channel estimation error variance for different SNR and different values of β.

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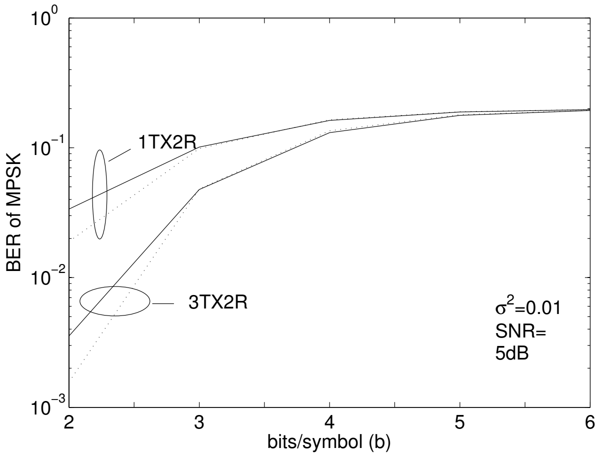

Fig. 6. BER performance for MPSK versus number of bits per symbol of different downlink systems over Weibull fading channel for both $\beta = 2$ and $\beta = 6$, respectively.

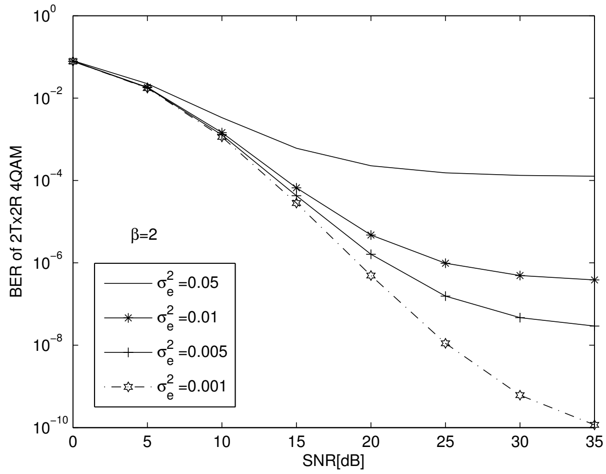

Fig. 8. Effect of channel estimation error variance on downlink BER over Weibull fading channel with $\beta = 2$ and the $2TX2R$ case.

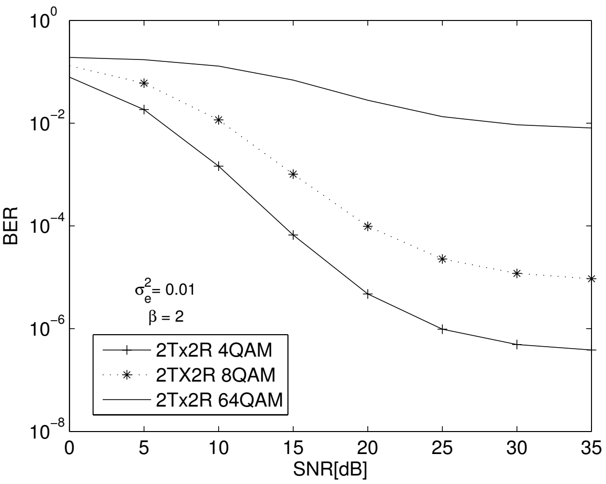

Fig. 7. Effect of M-ary size on downlink BER over Weibull fading channel with $\beta = 2$ and $\sigma_e^2 = 0.01$ for the $2TX2R$ case.

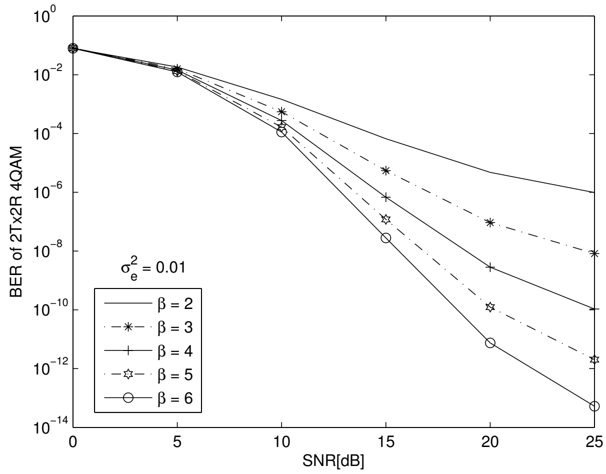

Fig. 9. Effect of fading severity on downlink BER over Weibull fading channel with $\sigma_e^2 = 0.01$ for the $2TX2R$ case.

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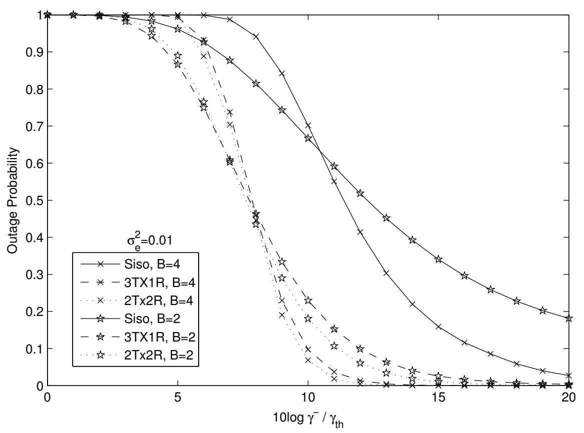

Fig. 10. Outage probability versus the normalized average SNR for different CDMA-SFBC downlink systems for $\beta = 4$ and $\beta = 2$ Weibull fading channel, $\sigma_e^2 = 0.01$, and $\gamma_{th} = 10$ dB.

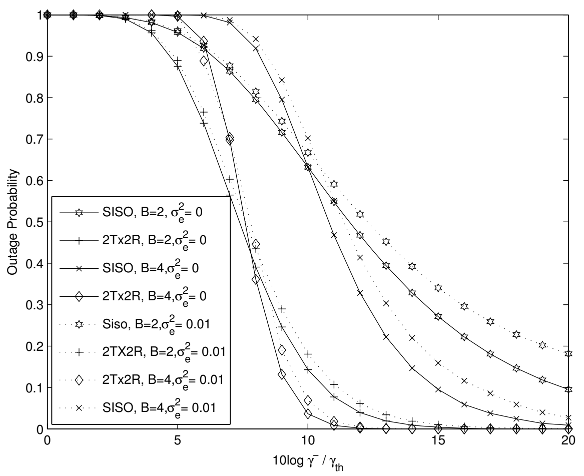

Fig. 11. Outage probability versus the normalize SNR for $\gamma_{th} = 10$ dB, for $\beta = 4$ and $\beta = 2$ with $\sigma_e^2 = 0$ and $\sigma_e^2 = 0.01$.

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