Bit Error Probability and Capacity Analysis of Space-Time Block Codes in Spatially Correlated MIMO Weibull Fading Channels

SUDAKAR SINGH CHAUHAN AND SANJAY KUMAR
Electronics and Communication Department
Birla Institute of Technology
Mesra, Ranchi
INDIA
sudakarnith@gmail.com, skumar@bitmesra.ac.in

Abstract: - In this paper we examine the effects of spatial fading correlation on bit-error probability (BEP) and channel capacity of orthogonal space–time block codes (STBCs) over multiple-input multiple-output (MIMO) Weibull fading channel. We derive the characteristic function (cf) of the signal-to-noise ratio (SNR) which is linear combination of Laplace transforms weighted by the eigenvalues of the channel correlation matrix, with each component corresponds to an underlying Gamma probability density function (pdf). By efficient use of this method the close-form BEP and capacity expressions are derived for STBC with M-ary phase shift keying and M-ary quadrature amplitude modulation (M-PSK, M-QAM) over Weibull fading channels in the presence of spatial fading correlation.

Key-Words: - Space-Time Block Codes (STBC), bit error probability (BEP), channel capacity, correlated Weibull fading, Multiple-input multiple-output (MIMO).

1 Introduction

Multiple-input multiple-output (MIMO) systems have attracted remarkable attention since authors in [1-2] analyzed its potential to achieve spectral efficiency and reliability of the system. In this regard space-time block code (STBC) introduced in [3] for transmission with two transmit antennas that obtain high diversity gain using a simple maximum-likelihood (ML) decoder and is generalized in [4]. SNR maximization using STBC codes is explored in [5]. The performance gap between the non ergodic STBC channel capacity and the actual MIMO channel capacity was analyzed in [6]. By efficient use of moment generating function (MGF), the exact symbol error probability (SEP) of STBCs with M-ary modulation schemes over keyhole Nakagami fading channels was evaluated in [7]. In [8], the system capacity and error probability of orthogonal STBC with M-ary modulation were analyzed. The bit error rate (BER) of STBC has been derived in [9] in the case of correlated Rayleigh channel, then the upper bounds on the BERs in a correlated Rayleigh fading was studied in [10]. In [11], author presented closed-form BER expressions for correlated Nakagami-*m* fading channels. The Weibull distribution is interesting model in reliability engineering and has recently drawn much attention in experimental fading channel measurements for both indoor and outdoor radio propagation domains [12-13].

The BEP performance of STBC over correlated Weibull fading channel has not been considered in the open literature. Thus, this paper fills the gap by presenting an analytical performance study of the STBC MIMO over correlated Weibull fading channel. We first analytically investigate the effects of correlated Weibull fading on the BEP performance of STBC, for M-PSK and M-QAM modulation schemes from an SNR perspective based upon the equivalent scalar channel induced by the STBC. Using the pdf of the SNR in Weibull fading channel, closed form bit error probabilities have been outlined for various combinations of modulation in the presence of fading correlation. Further we derive closed-form expression for the channel capacity of this transmit diversity scheme under correlated Weibull fading.

The remainder of this paper is organized as follows: in section 2 the STBC system and the channel model is presented. Section 3 derives the cf of the SNR at the output of the STBC decoder in the presence of correlated Weibull fading. In Section 4, we analyze the close-form expressions for the BEP of M-PSK and M-QAM modulations as well as the closed-form channel capacity of STBC under correlated Weibull fading is derived. Finally, section 5 provides numerical results showing the effects of correlation on the performance of STBC, followed by conclusion presented in section 6.

2 STBC System and Channel Model

Let a multiple antenna system with M_t transmit antennas and N_r receive antennas. R information bits are mapped as symbols $s_1, s_2, ... s_R$ which are chosen from the M-ary signal constellation with average power P_s. We assume that the channel is frequency non-selective, with perfect channel statistics available at the receiver. Hence, $\{s_n\}_{n=1}^{R}$ are encoded by a space-time block codes defined by a $T \times M_t$ column orthogonal transmission matrix **G**

$$G = \begin{pmatrix} g_{11} & g_{12} & \cdots & g_{1M_t} \\ g_{21} & g_{22} & \cdots & g_{2M_t} \\ \cdot & \cdot & \cdots & \cdot \\ g_{T1} & g_{T2} & \cdots & g_{TM_t} \end{pmatrix} \quad (1)$$

where the entries g_{ij}, $i = 1........M_t$ & $j = 1.......T$ represents a combination of the signal constellation components and their conjugates [7]. Since T time slots are require transmitting R symbols, the code rate is given by

$$R_c = R/T \quad (2)$$

In [4], code rate $1, 1/2$, and $3/4$ STBCs are given for two, three, and four transmit antennas, and are denoted as G_2, G_3, G_4, H_3 and H_4, respectively. At any time nT, the received signal is expressed as

$$R_{nT} = HG^T + w_{nT} \quad (3)$$

where received signal R_{nT} is an $N_r \times T$ matrix, G^T is the transpose with size $M_t \times T$ and w_{nT} is an $N_r \times T$ noise matrix, $H = \lfloor h_{ij} = x_{ij} \exp(k\phi_{ij}) \rfloor$ is an $N_r \times M_t$ fading channel coefficient matrix which exhibit mutual correlation. The $N_r M_t$ path gain x_{ij} are Weibull distributed according to the pdf given by [14]

$$p_{X\,ij}(x) = \frac{\beta_{ij}}{\Omega_{ij}} x^{\beta_{ij}-1} \exp\left(-\frac{x^{\beta_{ij}}}{\Omega_{ij}}\right) \quad (4)$$

where the average fading power $\Omega_{ij} = E\left(X_{ij}^{\beta_{ij}}\right)$ and E(.) denoting expectation. β_{ij} is the fading parameter and reduces to the Rayleigh distribution when $\beta = 2$. Moreover $E\left[h_{ij}\right]^2 = \beta/2$ and average SNR per channel is defined as $\overline{\gamma_c} = \beta P/2N_0$ where P is average power per symbol of the transmit antenna. The STBC for complex symbols was given as in [6]

$$r_{nT} = \|H\|_F^2 x_{nT} + v_{nT} \quad (5)$$

where r_{nT} is the $2S \times 1$ complex matrix after STBC decoding from the output matrix R_{nT}, x_{nT} is the input $S \times 1$ complex transmit matrix, and v_{nT} is complex Gaussian noise with zero mean and variance $\|H\|_F^2 N_0$. $\|H\|_F^2 = tr\left(HH^H\right) = \sum_{j=1}^{M_t}\sum_{i=1}^{N_r}\left\|h_{ij}\right\|^2$ is the squared Frobenius norm of the channel gain. The scalar additive white Gaussian noise (AWGN) channel with a STBC is given as

$$r_{nT} = \frac{1}{R_c}\|H\|_F^2 x_{nT} + v_{nT} \quad (6)$$

where v_{nT} is complex Gaussian noise with zero mean and variance $(1/R_c)\|H\|_F^2 N_0/2$ in each real dimension. Due to orthoganality of rows of **G**, we have $P_s = 2P/\beta M_t R_c$. Therefore, at the receiver the effective instantaneous SNR, denoted as γ_s is

$$\gamma_s = \frac{2P}{\beta M_t R_c N_0}\|H\|_F^2 = \frac{2}{\beta M_t R_c}\sum_{i=1}^{M_t}\sum_{j=1}^{N_r}\overline{\gamma_c}\left\|h_{ij}\right\|^2$$
$$= \frac{2}{\beta K}\overline{\gamma_c}\sum_{i=1}^{M_t}\sum_{j=1}^{N_r}\gamma_{ij} \quad (7)$$

where $K = M_t R_c$ and γ_{ij} is the instantaneous SNR of each fading channel.

3 Characteristic Function of the output SNR

The effective output SNR γ_s (7) using the definition of matrix Frobinius norm, is the sum of elementary SNR where $\gamma_{ij} = \left|h_{ij}\right|^2$. The SNR of the equivalent scalar AWGN channel is a sum of $N_r M_t$ correlated Gamma random variables according to (7) due to the correlated Weibull fading assumption and thereby follows a multivariate Gamma distribution. In STBC the spatial correlation can be defined as $N_r M_t \times N_r M_t$ covariance matrix

$$R_{cc} = E\left[\left(vec(\Gamma) - E[vec(\Gamma)]\right)\left(vec(\Gamma) - E[vec(\Gamma)]\right)^T\right] \quad (8)$$

where $vec(.)$ maps the elements of $N_r \times M_t$ matrix Γ into the $N_r M_t \times 1$ column vector. Let $N_r M_t \times 1$ column complex matrix $X_l = \lfloor X_{l|1}, X_{l|2}, ...X_{l|N_r M_t} \rfloor$, $l = 1, 2, ..., \beta/2$ be $\beta/2$ i.i.d. zero-mean circularly symmetric, each with a distribution $CN\left(0_{N_rM_t\times 1}, R_{cc}\right)$.

Thus $E\left[X_l\right]=0_{N_rM_t\times 1}$ and $E\left[X_l X_l^H\right]=R_{cc}$. Now, characterizing the $N_rM_t\times N_rM_t$ random Hermitian matrix T whose diagonal elements are real and positive as

$$T=\sum_{l=1}^{\beta/2} X_l X_l^H \qquad (9)$$

Consider random variable γ be the trace of the matrix T and is given by

$$\gamma = trace(T)=\sum_{l=1}^{\beta/2} X_l X_l^H \qquad (10)$$

The cf Ψ_T of the random matrix T can be specified by assuming a $N_rM_t\times N_rM_t$ Hermitian matrix Ω as follows [15]:

$$\Psi_T(i\Omega)=E\left[\exp\{i\, trace(T\,\Omega)\}\right] \qquad (11)$$

$$=E\left[\exp\left\{i\, trace\left(\sum_{l=1}^{\beta/2} X_l X_l^H\,\Omega\right)\right\}\right] \qquad (12)$$

$$=\prod_{l=1}^{\beta/2} E\left[\exp\{i\, trace\left(X_l X_l^H\,\Omega\right)\}\right] \qquad (13)$$

$$=\prod_{l=1}^{\beta/2} E\left[\exp\{i\, X_l^H\,\Omega X_l\}\right] \qquad (14)$$

By utilizing the result of [16], the cf of Hermitian matrix, $E\left[\exp\{i\, X_l^H\,\Omega X_l\}\right]$ is equal to $\det\{I_{N_rM_t}-i\Omega R_{cc}\}^{-1}$ where $\det\{.\}$ denotes the determinant operator. Thus (14) simplifies to

$$\Psi_T(i\Omega)=\det\{I_{N_rM_t}-i\Omega R_{cc}\}^{-\beta/2} \qquad (15)$$

Taking the special case of $\Omega = w\,I_{N_rM_t}$ where w is any real number into (14), we get

$$\Psi_T\left(i\,w I_{N_rM_t}\right)=E\left[\exp\left\{i\,w\sum_{l=1}^{\beta/2} X_l^H\,X_l\right\}\right]=E\left[\exp\{i\,w\,\gamma\}\right]$$

To determine the cf of γ_s (7) which can easily be derived from that of γ (10), using the change of random variables $\gamma \mapsto \gamma_s = \frac{2\,\overline{\gamma_c}}{\beta K}\gamma$

$$\Rightarrow \Psi_\gamma(i\,w)=\Psi_{\gamma_s}\left(i\,w\frac{\beta K}{2\,\overline{\gamma_c}}\right) \qquad (16)$$

Using this result, the cf of the scalar AWGN channel can be evaluated as follows:

$$\Psi_{\gamma_s}(i\,w)=\Psi_\gamma\left(i\,w\frac{2\,\overline{\gamma_c}}{\beta K}\right)$$

$$=\det\left\{I_{N_rM_t}-i\,w\frac{2\,\overline{\gamma_c}}{\beta K}R_{cc}\right\}^{-\beta/2}$$

$$\Psi_{\gamma_s}(iw)=\det\left\{I_{N_rM_t}-w\frac{2\,\overline{\gamma_c}}{\beta K}R_{cc}\right\}^{-\beta/2} \qquad (17)$$

The equation (17) is valid for any real positive number. The cf may be written in term of the P distinct eigenvalues $\lambda_1,\lambda_2,.......,\lambda_P$ of the complex covariance matrix R_{cc} and repeated μ_p times. Then (17) can be written using [17] as

$$\Psi_{\gamma_s}(iw)=\frac{1}{\prod_{p=1}^{P}\left(I_{N_rM_t}-iw\frac{2\,\overline{\gamma_c}}{\beta K}\lambda_p\right)^{\mu_p\beta/2}} \qquad (18)$$

By using a partial fraction expansion (18) can be written as,

$$\Psi_{\gamma_s}(iw)=\sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2}\frac{\xi_{pj}}{\left(I_{N_rM_t}-iw\frac{2\,\overline{\gamma_c}}{\beta K}\lambda_p\right)^{j}} \qquad (19)$$

Where

$$\xi_{pj}=\frac{1}{\left(\mu_p\,\beta/2-j\right)!\left(-\frac{2\,\overline{\gamma_c}}{\beta K}\lambda_p\right)^{\mu_p\beta/2-j}}$$

$$\times\frac{\partial^{\mu_p\beta/2-j}}{\partial w^{\mu_p\beta/2-j}}\left[\left(1-w\frac{2\,\overline{\gamma_c}}{\beta K}\lambda_p\right)^{-\mu_p\beta/2}\Psi_{\gamma_s}(iw)\right]\Bigg|_{w=-\frac{\beta K}{2\,\overline{\gamma_c}\lambda_p}} \qquad (20)$$

Taking the inverse Laplace transform of (19), we will get the pdf of γ_s by utilizing the linearity of the Laplace transform [18]. The pdf of γ_s can be written as

$$p(\gamma_s)=\sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2}\xi_{pj}\frac{\gamma_s^{j-1}e^{-\frac{\beta K}{2\overline{\gamma_c}\lambda_p}\gamma_s}}{\Gamma(j)\left(\frac{2\overline{\gamma_c}\,\lambda_p}{\beta K}\right)^{j}} \qquad (21)$$

4 BEP of STBC in Correlated Weibull Fading

In this section, we derive closed-form BEP of STBC with M-PSK or M-QAM signal constellations and the channel capacity in the presence of correlated Weibull fading.

4.1 Probability of Error for M-PSK:

Let $P_M(\gamma_s)$ denote the probability of error of a M-ary signal constellation with STBC in an AWGN channel. The probability of error with correlated Weibull fading can be obtained by averaging $P_M(\gamma_s)$ over the pdf of γ_s

$$P_{STBC,M} = \int_0^\infty P_M(\gamma_s) p(\gamma_s) d\gamma_s \qquad (22)$$

The BEP of M-ary PSK for AWGN channels is given in [19],

$$P_{AWGN,M-PSK}(\gamma_s) = 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) - \frac{1}{\pi}\int_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} e^{-\gamma_s \frac{\sin^2 \pi/M}{\cos^2\theta}} d\theta \qquad (23)$$

For large value of M and large SNR, the BEP of M-ary PSK in AWGN channel can be approximated as

$$P_M(\gamma_s) \approx 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) \qquad (24)$$

Inserting (24) & (21) into (22) we get,

$$P_{STBC,M-PSK} \approx \int_0^\infty 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) \times \sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2} \xi_{pj} \frac{\gamma_s^{j-1} e^{-\frac{\beta K}{2\overline{\gamma_c}\lambda_p}\gamma_s}}{\Gamma(j)\left(\frac{2\overline{\gamma_c}\lambda_p}{\beta K}\right)^j} d\gamma_s \qquad (25)$$

In order to evaluate (25), we are using the result [24]

$$\int_0^\infty Q\left(\sqrt{at}\right) t^{P-1} e^{-t/u} dt = \frac{1}{2}u^P \Gamma(P)\left[1 - \sum_{k=0}^{P-1}\mu\left(\frac{1-\mu^2}{4}\right)^k \binom{2k}{k}\right] \qquad (26)$$

Thus, the BEP of M-PSK can be obtained as

$$P_{STBC,M-PSK} = \eta \sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2} \xi_{pj}\left[1 - \sum_{k=0}^{j-1}\mu_p\left(\frac{1-\mu_p^2}{4}\right)^k \binom{2k}{k}\right] \qquad (27)$$

where $\eta = 1/2$ for $M = 2$ & $\eta = 1$ for $M > 2$ and

$$\mu_p = \sqrt{\frac{\sin^2\frac{\pi}{M}\overline{\gamma_c}\lambda_p}{\beta/2 + \sin^2\frac{\pi}{M}\overline{\gamma_c}\lambda_p}}$$

4.2 Probability of Error for M-QAM:

The BEP of rectangular QAM signal constellations is given in [20-21] as

$$P_{STBC,M-QAM} = 1 - \left(1 - P_{STBC,\sqrt{M}-PAM}\right)^2 \qquad (28)$$

where

$$P_{STBC,\sqrt{M}-PAM} = 2\left(1 - \frac{1}{\sqrt{M}}\right) Q\sqrt{\frac{3}{M-1}\gamma_s} \qquad (29)$$

Inserting (29) & (21) into (22), we get

$$P_{STBC,\sqrt{M}-PAM} = \int_0^\infty 2\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1}\gamma_s}\right) \times \sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2} \xi_{pj} \frac{\gamma_s^{j-1} e^{-\frac{\beta K}{2\overline{\gamma_c}\lambda_p}\gamma_s}}{\Gamma(j)\left(\frac{2\overline{\gamma_c}\lambda_p}{\beta K}\right)^j} d\gamma_s \qquad (30)$$

by using (26), we get

$$P_{STBC,\sqrt{M}-PAM} = \left(1 - \frac{1}{\sqrt{M}}\right)\sum_{p=1}^{P} \times \sum_{j=1}^{\mu_p\beta/2}\xi_{pj} \times \left[1 - \sum_{k=0}^{j-1}\mu_p\left(\frac{1-\mu_p^2}{4}\right)^k \binom{2k}{k}\right] \qquad (31)$$

where $\mu_p = \sqrt{\frac{3\overline{\gamma_c}\lambda_p}{\beta/2\left(2M - 2 + 3\overline{\gamma_c}\lambda_p\right)}}$

Thus inserting (31) into (28), closed form BEP for rectangular M-ary QAM can be evaluated.

4.3 Channel Capacity:

The capacity of a MIMO wireless system over a fading channel is given in [1] as

$$C = E\left[\log_2 \det\left(I + \frac{E_s}{M_t N_0} HH^H\right)\right] \quad b/s/Hz \qquad (32)$$

Where I is an identity matrix with dimension N_r, $\det(y)$ denotes the determinant of matrix y, and $(.)^H$ denotes matrix transpose and conjugate. The capacity of the equivalent STBC channel in (5) is given in (bits per second per hertz) as [6]

$$\langle C\rangle^{STBC} = E\left[R_c \log_2 \det\left(I + \frac{E_s}{R_c M_t N_0}\|H\|_F^2\right)\right] \quad b/s/Hz$$
$$= R_c^{'} E\left[\ln(1+\gamma_s)\right] \quad b/s/Hz \qquad (33)$$

where $R_c^{'} = R_c/\ln(2)$.

The capacity of the STBC channel can be written as

$$\langle C\rangle^{STBC} = R_c^{'}\int_0^\infty \ln(1+\gamma_s) p(\gamma_s) d\gamma_s \qquad (34)$$

Inserting (21) into (34), the closed-form channel capacity of STBC is given as

$$\langle C\rangle_{ora} = R_c^{'}\sum_{p=1}^{P}\sum_{j=1}^{\mu_p\beta/2}\frac{\xi_{pj}}{\Gamma(j)\left(\frac{2\overline{\gamma_c}\,\lambda_p}{\beta K}\right)^j}$$

$$\times\int_0^\infty \ln(1+\gamma_s)\gamma_s^{j-1}e^{-\frac{\beta K}{2\overline{\gamma_c}\,\lambda_p}\gamma_s}\,d\gamma_s \qquad (35)$$

By using the result in [22], the channel capacity can be obtain as in (37)

$$\int_0^\infty \ln(1+t)t^{x-1}e^{-pt}\,dt = (x-1)!e^p\sum_{k=1}^{x}\frac{\Gamma(-x+k,p)}{p^k} \qquad (36)$$

$$\langle C\rangle_{ora} = R_c^{'}\sum_{p=1}^{P}e^{\left(\frac{\beta K}{2\overline{\gamma_c}\,\lambda_p}\right)}\sum_{j=1}^{\mu_p\beta/2}\xi_{pj}\sum_{k=1}^{j}\frac{\Gamma\left(k-j,\frac{\beta K}{2\overline{\gamma_c}\,\lambda_p}\right)}{\left(\frac{\beta K}{2\overline{\gamma_c}\,\lambda_p}\right)^k} \qquad (37)$$

5 Numerical Results

In this section, we provide numerical results showing the effects of spatial fading correlation on the probability of error and capacity performance of STBC. Our results of section 4 are accurate for any complex covariance matrix R_{cc} and any orthogonal design. We consider Gaussian model [23], with correlation coefficient is

$$\rho = \exp\left[-\frac{k}{2}(i-j)^2\left(\frac{d}{\lambda}\right)^2\right], i,j = 1,\dots\dots\dots,N_rM_t \quad (38)$$

where ρ is such that $|\rho|<1$, d is the span between two adjacent antenna and λ is the wavelength of the carrier. The coefficient $k = 21.4$ is chosen to give the same $-3\,dB$ point with the Bessel correlation model. In Fig. 1 the BEP of BPSK with STBC G_2 and one receive antenna is presented for correlated Weibull fading channel with $\beta = 2$ (Rayleigh). There is approximately a 13 dB gain in SNR with independent fading channels over the fully correlated case at a BEP of 10^{-3}. In Fig. 2, the BEP of BPSK with STBC G_2 and one receive antenna is presented for correlated Weibull fading channel with $\beta = 3$. There is approximately a 10 dB gain in SNR with independent fading channels over the fully correlated case at a BEP of 10^{-5}. Comparing Figs. 1 and 2, it is interesting to note that the fully correlated Weibull fading channel with $\beta = 3$ has the same performance as the independent Weibull fading channel with $\beta = 2$.

Fig. 3 shows the BEP of STBCs G_3, G_4, H_3 and H_4 with QPSK and two receive antennas over correlated Weibull fading channels with $\beta = 3$. The correlation parameter is set to 0.9. In all the figures, it can be observed that the correlation degrades the BEP performance and the performance of STBC's varies with the fading parameter β and improves with the increasing value of β.

Fig. 4 depicts the channel capacity using STBC G_2 over a correlated Weibull fading channel with $\beta = 2$ (Rayleigh) with one receive antenna. It illustrated that when the span between adjacent antennas increases the capacity enhances. However, when the span between two adjacent antennas is larger than half the wavelength, a further increase in the seperation has no valid effect on channel capacity. In all figure $\frac{d}{\lambda}$ is denoted by $\frac{d}{lamda}$ and β is denoted by $beta$.

6 Conclusion

We analyzed the impact of fading correlation on the BEP performance. Analytical closed-form expression of the average BEP performance of STBCs over correlated Weibull fading channel has been derived. SNR gain of 13 dB in BPSK at a BEP of 10^{-3} & SNR gain of 10dB in BPSK at a BEP of 10^{-5} for the same antenna configuration, for different β values is observed. It can be observed that the correlation deteriorates the BEP performance when the correlation between the branches increases. The performance of STBC's varies with the fading parameter β and improves with the increasing value of β. Finally, the closed-form channel capacity of STBC over Weibull fading has been derived in the presence of fading correlation. Numerical results show that, the reduction in terms of capacity is negligible in case of an exponential correlation model, when the correlation coefficient between adjacent antenna elements is smaller. The capacity increases as the physical distance between the two adjacent antennas increases when the distance between adjacent antennas is less than half the wavelength.

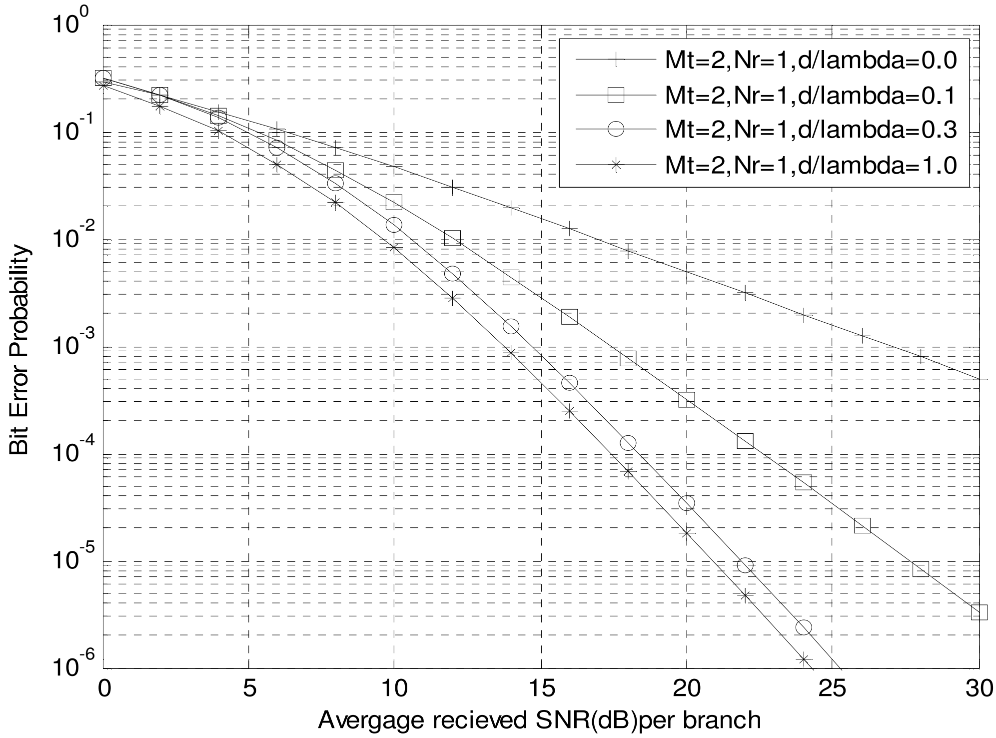

Fig.1. BEP of STBC G_2 with one receive antenna over a correlated Weibull fading channel (β=2) using BPSK

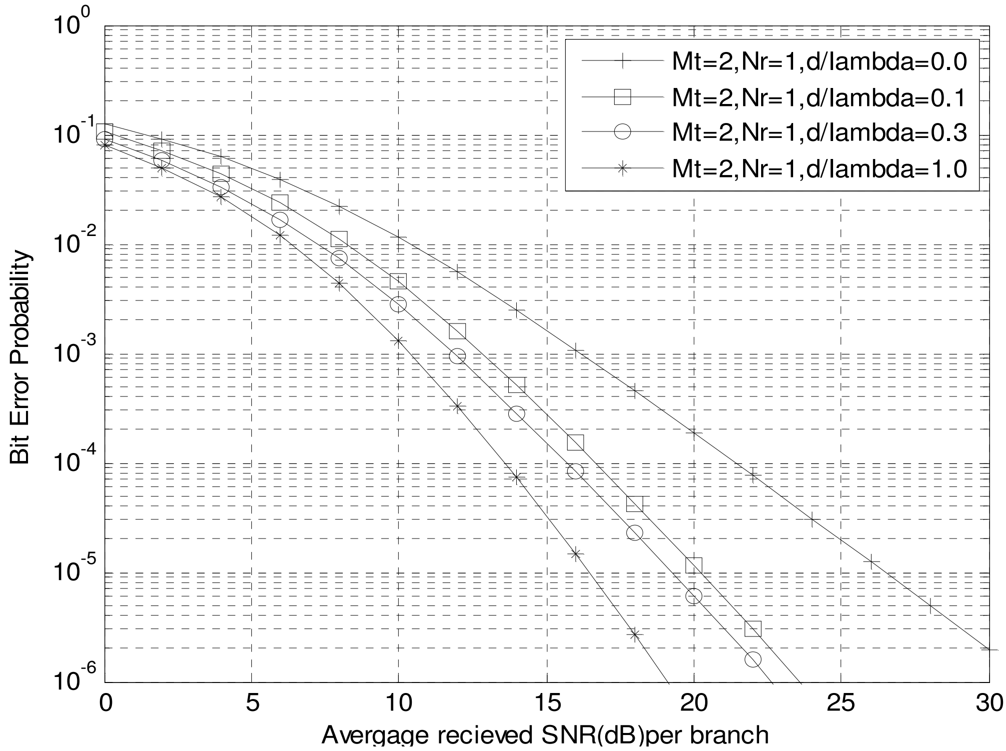

Fig.2. BEP of STBC G_2 with one receive antenna over a correlated Weibull fading channel (β=3) using BPSK

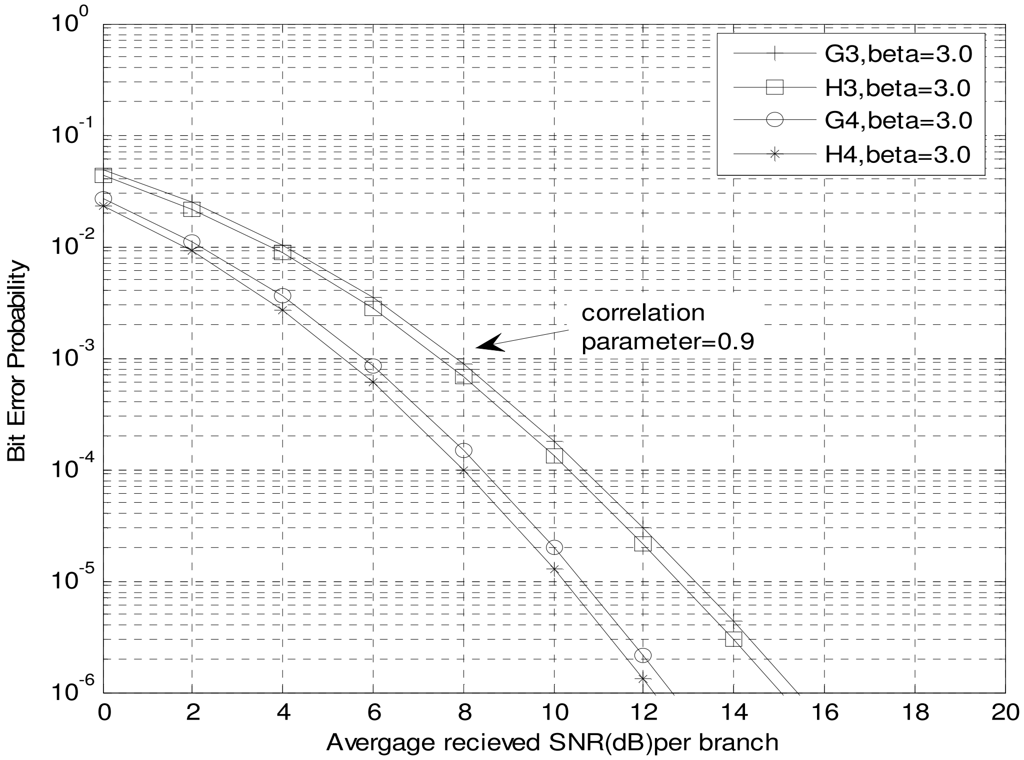

Fig.3. BEP of various STBC with QPSK and two receive antenna over a correlated Weibull fading channel (β=3)

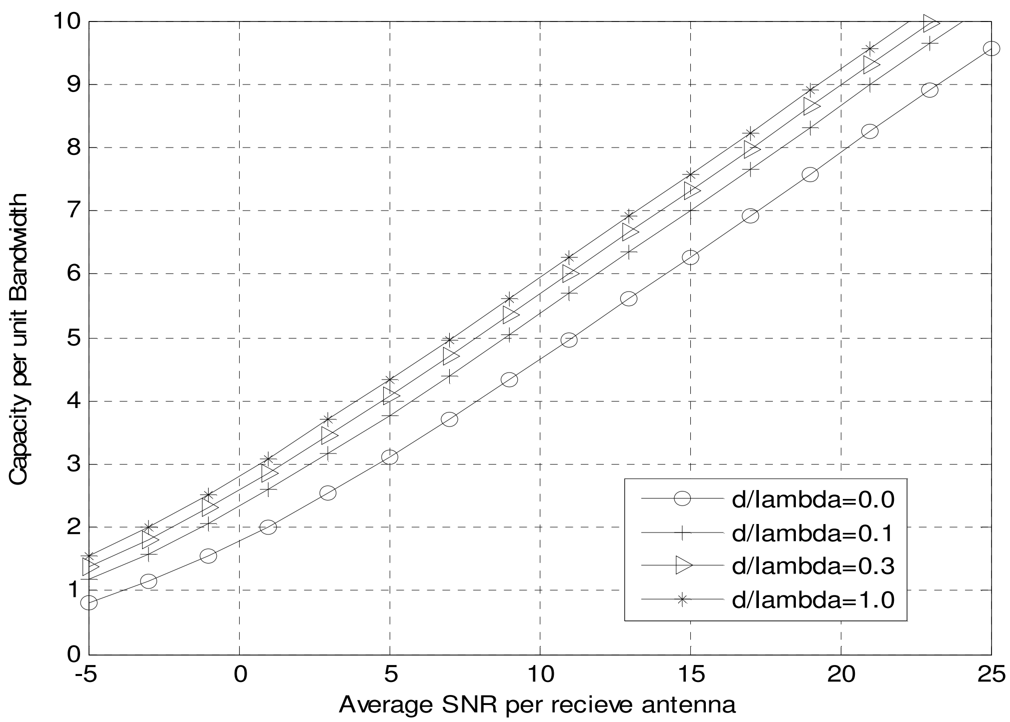

Fig.4. Channel capacity of STBC G_2, one receive antenna over a correlated Weibull fading channel (β=2)

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