Analytical Performance Evaluation of Space Time Coded MIMO OFDM Systems Impaired by Fading and Timing Jitter

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Abstract **— An analytical approach is presented to determine the impact of time selective fading, timing jitter and additive white Gaussian noise (AWGN) on the bit error rate (BER) performance of an orthogonal frequency-division multiplexing (OFDM) system with differential quaternary phase-shift keying (DQPSK), differential phase-shift keying (DPSK) and quaternary phase-shift keying (QPSK) modulation. The expression for the conditional BER conditioned on a given timing error and fading, is derived and the average BER is evaluated. The BER performance results are evaluated for different values of fading and jitter. The performance of the OFDM system in Rayleigh and Rician fading channels is also compared. Analytical approach is also developed to evaluate the BER performance of a quasi-orthogonal- space-time block coded OFDM system having multiple transmitting and single receiving antennas. The analysis is extended for a multiple-input multiple-output (MIMO)-OFDM system using the "selection method" for combining multiple receiving antennas, which offers significant improvement in the system performance. The effects of increase in number of OFDM subcarriers and increase in Doppler frequency are also investigated.**

Index Terms **— Convolutional coding, intersymbol interference, MIMO, OFDM, Rayleigh fading, STBC, timing jitter.**

I. Introduction

Orthogonal frequency-division multiplexing (OFDM) is effective in avoiding intersymbol interference caused by multipath delay. However, it is sensitive to time-selective fading which destroys the orthogonality among different subcarriers in one OFDM symbol leading to intercarrier interference. OFDM signal is also degraded by timing jitter caused by time synchronization error at the receiver. Several research works have been carried out during the last few years on the performance evaluation of an OFDM system over fading channels in [1]-[5]. The effect of timing jitter, on the performance of an OFDM system without considering multipath fading, is also reported [6], [7]. The performance of quasi-orthogonal-space-time coded (QOSTC) system over fast fading channel is investigated for single-carrier systems in [8]. The performance of QOSTC-OFDM system over fading channel is reported in terms of carrier to interference and signal to interference and noise ratios [9]. The BER is also evaluated through simulations. However, in [9], the jitter effect is ignored and only a single receiving antenna is used.

In this paper, we develop an analytical approach in order to find the BER of an OFDM system and a space-time block coded (STBC)-OFDM system considering all three channel impairments like AWGN, fading and jitter in fading environment. We extend the analysis for a multiple-input multiple-output (MIMO)-OFDM system with switching/selection method for combining multiple receiving antennas. We also apply convolution coding to evaluate the effectiveness of coding in minimizing the effect of system impairments.

II. System Model

The STBC-OFDM system model considered for analysis is shown in Fig. 1.

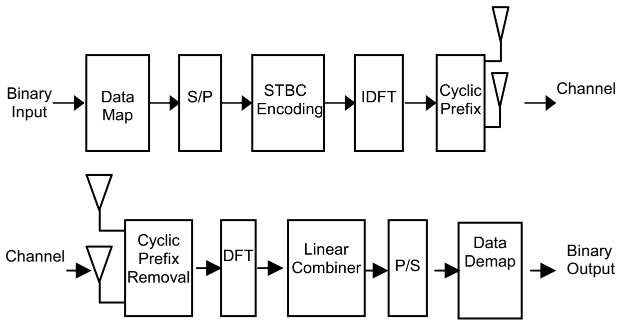

Fig. 1. Block diagram of the system

Binary input data is mapped to modulation symbols. These symbols are serial-to-parallel converted and then

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mapped to a matrix by using a quasi-orthogonal STBC with constellation rotation scheme. An inverse Fourier transform is used to find the corresponding time waveform. The guard period is then added to reduce the intersymbol interference (ISI). This guard period is a cyclic extension of the symbol to be transmitted. After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM. The symbols are transmitted from the multiple transmitting antennas simultaneously during every OFDM symbol period.

The receiver basically does the reverse operation to the transmitter. The signal is received by two receiving antennas. Diversity combiner at the receiver selects the best instantaneous signal of the two antennas. The received signal can be detected through differential or coherent scheme.

III. Theoretical Analysis of BER

For a stand alone OFDM system, the STBC encoding block and linear combiner block in Fig. 1, will not exist. Considering such an OFDM system, the expression of signal-to-noise plus interference power ratio (SNIR) without timing error can be expressed as [5]:

$$\text{SNIR}=\frac{1}{\frac{(k+1)(1+\delta_c)}{\frac{2E_b}{N_0}}+\frac{(\pi F_d T_s)^2}{2}+\frac{(\pi F_d T_s)^2}{6(1+\delta_c)^2}} \tag{1}$$

where F_d is the maximum Doppler frequency, N_0 is the Gaussian noise (AWGN), E_b is the bit energy, and k is the Rician paramere/factor. In (1), T_s is the symbol duration and δ_c is the guard interval ratio of an OFDM symbol. Here intra-symbol interference (I_s) and intercarrier interference (I_c) are considered as:

$$I_s=\frac{(\pi F_d T_s)^2}{2} \tag{2}$$

$$I_c=\frac{(\pi F_d T_s)^2}{6(1+\delta_c)^2} \tag{3}$$

By expressing the intercarrier interference component in terms of number of OFDM subcarriers (N_s), the expression of SNIR in (1), is modified as follows:

$$\text{SNIR}=\frac{1}{\frac{(k+1)(1+\delta_c)}{\frac{2E_b}{N_0}}+\frac{(\pi F_d T_s)^2}{2}+\sum_{n=1}^{N_s}\frac{1}{n^2}(F_d T_f)^2} \tag{4}$$

where T_f is the effective symbol period. To incorporate the jitter effect along with fading and AWGN, the jitter term is added in the equation of SNIR. In any communication system, timing jitter causes the signal power to degrade by a factor of (1- ε) over a time slot. The jitter also causes interference, which is added as $E_b\,\varepsilon$. Here ε is the timing error normalized by T_s, i.e. ($\varepsilon=\Delta\ /\ T_s$) and E_b is the bit energy. However, in fading environment, the received signal energy is random depending on random fade, but the noise energy remains unchanged. The received bit energy E_b is the product of input bit energy E_{in} and the multiplicative fade α^2 , i.e. $E_b = E_{in}\,\alpha^2$. So, with this modification, the expression of SNIR for a stand alone OFDM system can be expressed as follows:

SNIR (ε,α) =

$$\frac{1}{\frac{(k+1)(1+\delta_c)}{\frac{2(E_{in}\alpha^2)(1-\varepsilon)}{N_0}}+\frac{(\pi F_d T_s)^2}{2}+\sum_{n=1}^{N_s}\frac{1}{n^2}(F_d T_f)^2+(E_{in}\alpha^2)\varepsilon} \tag{5}$$

In the presence of time-varying fading, SNIR for quasi-orthogonal STBC-OFDM system has an expression as [9]:

SNIR=

$$\frac{4\sum_{l=0}^{L-1}[N_s+2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi\, iF_d T_s)]e^{-\frac{\tau l}{\tau rms}}}{4\sum_{k'=1}^{N_S-1}\sum_{l=0}^{L-1}[N_s+2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi\, iF_d T_s)\cos(\frac{2\pi}{N_s}k'i)\ e^{-\frac{\tau l}{\tau rms}}]+\sigma^2} \tag{6}$$

The above expression is considered for unit symbol energy and four number of transmitting antennas. In (6), τ_l is the delay of the lth path normalized with respect to the OFDM symbol duration T_s, whereas τ_{rms} represents the root-mean square (rms) delay spread. In the expression, σ^2 represents the variance of AWGN. Now we consider E_S symbol energy with guard interval ratio δ_c and Rician parameter k. For DQPSK and QPSK, symbol energy is twice the bit energy, i.e. $E_S=2E_b$ and for DPSK, it is equal to E_b. So, for DQPSK and QPSK modulation, the equation of SNIR for a quasi-orthogonal STBC-OFDM system in (6), can be modified as follows:

SNIR=

$$\frac{N_T\sum_{l=0}^{L-1}[\{\frac{2E_b}{(k+1)(1+\delta_c)}\}\ \{N_s+2\sum_{i=1}^{N_S-1}(N_s-i)\ J_0(2\pi i F_d T_s)\}\ ]e^{-\frac{\tau l}{\tau rms}}}{N_T\{\frac{2E_b}{(k+1)(1+\delta_c)}\}\times[\sum_{k'=1}^{N_S-1}\sum_{l=0}^{L-1}\{N_s+2\sum_{i=1}^{N_S-1}(N_s-i)\ J_0\ (2\pi i F_d T_s)\cos(\frac{2\pi}{N_s}k'\,i)\}\ e^{-\frac{\tau l}{\tau rms}}]+\sigma^2} \tag{7}$$

where N_T is the number of transmitting antennas. For STBC-OFDM, jitter has the same effect as in OFDM systems. So, by simultaneously considering AWGN, jitter and fading, the expression of SNIR for a quasi-orthogonal STBC-OFDM system with DQPSK or QPSK modulation can be expressed as follows:

SNIR (ε,α) =

$$\frac{N_T\sum_{l=0}^{L-1}[\ \{\frac{(2E_{in}\alpha^2)(1-\varepsilon)}{(k+1)(1+\delta_c)}\}\ \{\ N_s+2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi i F_d T_s)\ \}\ ]\ e^{\frac{\tau l}{\tau rms}}}{N_T\{\frac{(2E_{in}\alpha^2)(1-\varepsilon)}{(k+1)(1+\delta_c)}\}\times[\sum_{k'=1}^{N_S-1}\sum_{l=0}^{L-1}\{N_s+2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi i F_d T_s)\cos(\frac{2\pi}{N_s}k'i)\ \}e^{\frac{\tau l}{\tau rms}}]+\ (\sigma^2+E_{in}\alpha^2\varepsilon)} \tag{8}$$

Similarly, for a quasi-orthogonal STBC-OFDM system with DPSK modulation, the SNIR in presence of the impairments can be expressed as:

$$\mathrm{SNIR}\,(\varepsilon,\alpha) = \frac{N_T \sum_{l=0}^{L-1} \left[\left\{\frac{(E_{in}\alpha^2)(1-\varepsilon)}{(k+1)(1+\delta_c)}\right\} \left\{N_s + 2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi i F_d T_s)\right\} \right] e^{-\frac{\tau l}{\tau rms}}}{N_T\left\{\frac{(E_{in}\alpha^2)(1-\varepsilon)}{(k+1)(1+\delta_c)}\right\}\times \left[\sum_{k'=1}^{N_S-1}\sum_{l=0}^{L-1}\left\{N_s+2\sum_{i=1}^{N_S-1}(N_s-i)J_0(2\pi i F_d T_s)\cos\left(\frac{2\pi}{N_s}k'\,i\right)\right\} e^{-\frac{\tau l}{\tau rms}}\right] + (\sigma^2 + E_{in}\alpha^2\varepsilon)} \tag{9}$$

Following [5], the bit error rate (BER) performance for DQPSK/OFDM system over multipath fading channels can be evaluated in presence of jitter as:

$$P_e(\varepsilon,\alpha) = \frac{\{1-J_0(2\pi F_d T_s)\}\{\frac{SNIR(\varepsilon,\alpha)}{2}\}+1}{2\{\frac{SNIR(\varepsilon,\alpha)}{2}+1\}}\exp\{-\frac{k\,\frac{SNIR(\varepsilon,\alpha)}{2}}{\frac{SNIR(\varepsilon,\alpha)}{2}+1}\} \tag{10}$$

where $J_0(2\pi F_d T_s)$ is the time correlation function. Following [10], The BER performance for QPSK/OFDM system can be expressed as follows:

$$\mathrm{P_e}\,(\varepsilon,\alpha) = 0.5\ \mathrm{erfc}\sqrt{\mathrm{SNIR}\,(\varepsilon,\alpha)} \tag{11}$$

Similarly, the BER expression for DPSK/OFDM system can be evaluated as follows:

$$P_e(\varepsilon,\alpha) = 0.5\ \mathrm{e}^{-SINR(\varepsilon,\alpha)} \tag{12}$$

For a fixed value of α, the probability of bit error is $P_e\ (\alpha)$. This $P_e\ (\alpha)$ is considered as a conditional probability of error for a given value of channel attenuation α. For Rayleigh fading channel, α is Rayleigh distributed. Then the pdf of α is:

$$p\,(\alpha) = \frac{\alpha}{\sigma^2}\ \exp\left(-\frac{\alpha^2}{2\sigma^2}\right) \tag{13}$$

where σ is Rayleigh parameter. The mean and variance of the Rayleigh density function is a function of σ, i.e. mean =1.25 σ and variance =0.655 σ. For Rician fading channel, α is Rician distributed. Then the pdf of α is:

$$p\,(\alpha) = \frac{\alpha}{\sigma^2}\ \exp\left(\frac{-(\alpha^2+m^2)}{2\sigma^2}\right)\ I_0\left(\frac{\alpha m}{\sigma^2}\right) \tag{14}$$

where *Io* is the zeroth order Bessel function and $m^2=2k\sigma^2$. The pdf of zero mean Gaussian distributed jitter is

$$\mathrm{p}\,(\varepsilon) = \frac{1}{\sqrt{2\pi\sigma_\varepsilon^2}}\ \exp\left(\frac{-\varepsilon^2}{2\sigma_\varepsilon^2}\right) \tag{15}$$

where σ_ε^2 is the variance of jitter. The unconditional/average BER (P_e) can be calculated by averaging the conditional BER $P_e(\varepsilon,\alpha)$, over all possible values of α and ε:

$$P_e = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_e\ (\varepsilon,\alpha)\ \ p(\alpha)\ \ p(\varepsilon)\ \ d\alpha\ d\varepsilon \tag{16}$$

STBC-OFDM with transmitting diversity is transformed into MIMO-OFDM by addition of receiving diversity. For receiving diversity scheme, "selective" diversity combining method is utilized in wireless systems. Considering the average bit error probability without diversity as $P_{e1}(A)$, the average BER with diversity can be derived as [10]:

$$P_{e2}(A)=2P_{e1}(A) - P_{e1}(A/2) \tag{17}$$

where A denotes the average SNIR.

IV. Results and Discussion

Following the analytical approach, the bit error rate performance results are evaluated at a data rate of 1 Mbps per OFDM subcarrier with maximum Doppler frequency of 60 Hz in fading channel. Keeping number of subcarriers to sixteen and fading variance to 0.1, we compare the performance of the system with and without jitter. Fig. 2 shows the plots of BER vs. P_{in} (dBm) for DQPSK-OFDM system. From Fig. 2, it is noticed that the BER slightly degrades with increase in jitter. Fig. 3 and Fig. 4 show the plots of BER vs. P_{in} (dBm) for QPSK and DPSK systems respectively. The plots show that OFDM is robust against lower values of jitter variance but the BER is highly degraded when jitter is substantially high and results in BER floor. At a BER of 10^{-9}, the jitter effect is negligible for jitter variance σ_ε^2 <0.125 for both QPSK and DPSK modulation. It is found that the jitter effect is more pronounced in QPSK and DPSK than in DQPSK system. The amounts of penalty, suffered by the OFDM systems due to timing jitter, are shown in Fig. 5. It is noticed that the QPSK system suffers almost the same amount of power penalty as DPSK system for lower values of jitter variance and at higher values of jitter; DPSK suffers more penalty than QPSK.

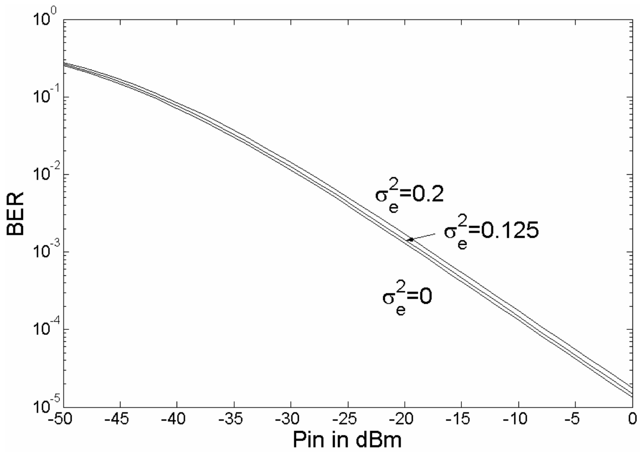

Fig. 2. BER vs. P_{in} (dBm) in presence of timing jitter for DQPSK-OFDM (N_s=16, F_d=60 Hz, σ_f^2=0.1, T_s=10^{-6}s)

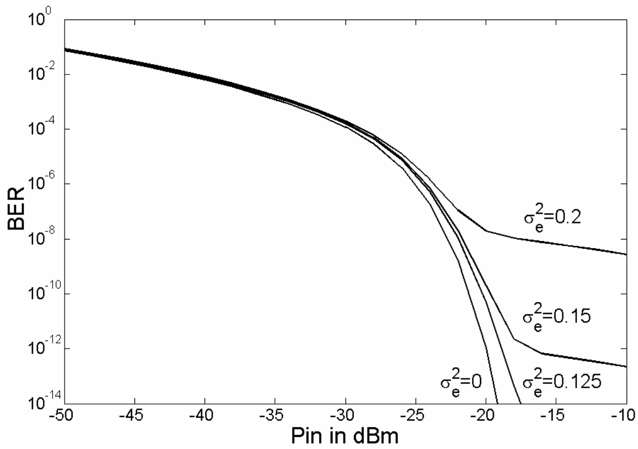

Fig. 3. BER vs. P_{in} (dBm) in presence of timing jitter for QPSK-OFDM (N_s=16, F_d=60 Hz, σ_f^2 =0.1, T_s=10^{-6}s)

To improve the system performance of a stand alone OFDM system, channel coding can be applied. From Table I, it is found that significant improvement of the BER performance is achieved by applying convolutional coding. Fig. 6 shows the plots of BER vs. P_{in} (dBm) for DQPSK system in Rayleigh and Rician channels. It is noticed that BER performance is better in Rician fading channel. This is because in Rician channel there exists one dominant line-of-sight path that is absent in Rayleigh channel. From Fig. 6, it is also revealed that BER performance improves with increase in Rician factor. For example, at 0 dBm input power and DQPSK mudualtion, the BER of a Rayleigh fading channel is 10^{-4} while Rician channels have a BER in the order of 10^{-5}, 10^{-6} and 10^{-7} for K=0 dB, 3 dB and 6 dB respectively. This result can be explained from the fact that higher Rician factor indicates more dominant line-of-sight path.

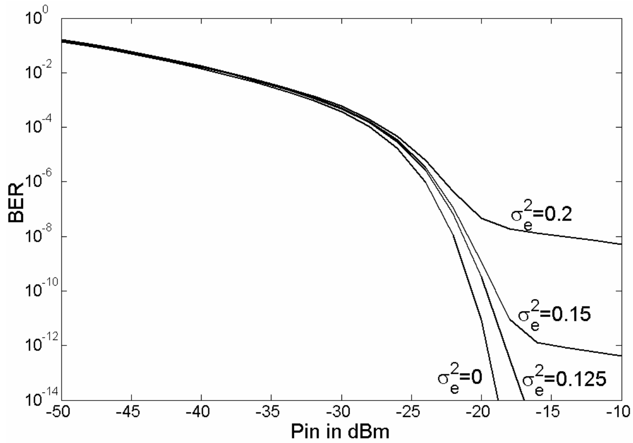

Fig. 4. BER vs. P_{in} (dBm) in presence of timing jitter for DPSK-OFDM (N_s=16, F_d=60 Hz, σ_f^2 =0.1, T_s=10^{-6}s)

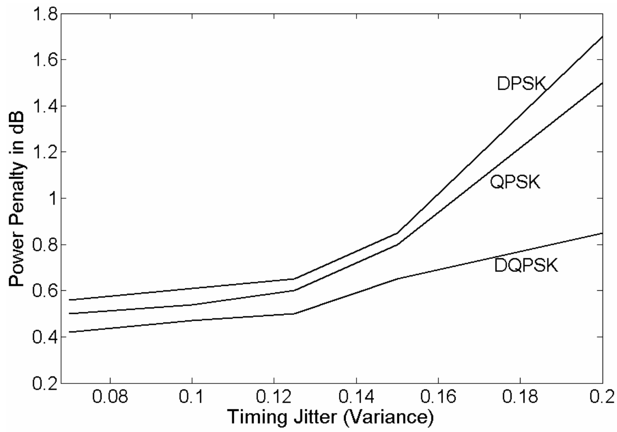

Fig. 5. Power penalty (in dB) due to jitter for OFDM systems with different modulation schemes at BER=10^{-6}

TABLE I
BER Improvement due to coding for OFDM

Modulation	Pin (dBm)	Uncoded BER	BER (R=1/2 K=6)	BER (R=1/2 K=7)
DQPSK	-20	10^{-3}	10^{-11}	10^{-13}
QPSK	-20	10^{-10}	10^{-36}	10^{-42}
DPSK	-20	10^{-10}	10^{-34}	10^{-40}

Fig. 7 shows the plots of BER vs. Pin (dBm) for the analysis presented by Sasamori in [5] and the proposed analysis of this work. The plots are considered for DQPSK system in Rayleigh channel with F_d=60 Hz and T_s=10^{-6}s. The proposed analysis shows more BER than the previous analysis presented by Sasamori [5], because the proposed analysis considers additional impairments of timing jitter (σ_ε^2=0.1) and channel attenuation (σ_f^2=0.1).

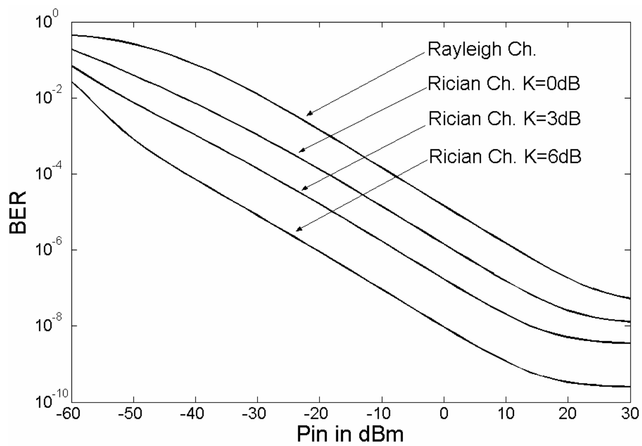

Fig. 6. BER vs. P_{in} (dBm) for Rayleigh and Rician channels for DQPSK-OFDM (N_s=16, F_d=60 Hz, σ_ε^2 =0.2, σ_f^2 =0.1, T_s=10^{-6}s)

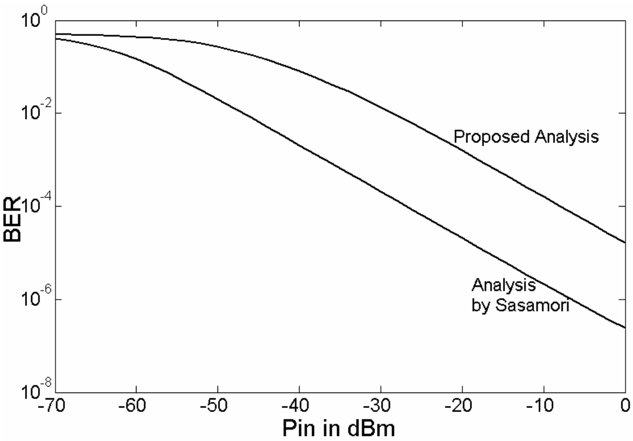

Fig. 7. BER vs. P_{in} (dBm) for previous and proposed analysis for OFDM

Fig. 8 shows the effect of timing jitter in a DQPSK STBC-OFDM system with one receiving antenna and fading variance of 0.1. From Fig 8, it is revealed that with the increase in jitter, the BER performance degrades and results in BER floor for higher values of jitter variance. At a jitter variance σ_ε^2 of 0.2, the BER floor occurs at about 10^{-3} compared to 10^{-4} for the case of without timing error. We also evaluate the similar performance of the system employing QPSK and DPSK modulation as shown in Fig. 9 and Fig. 10 respectively. It is noticed that the jitter causes BER floor in both the cases. It is found that the jitter effect is more pronounced in QPSK and DPSK than in DQPSK in terms of increase in BER floor. The amounts of penalty suffered by the systems due to timing jitter at BER=10^{-8} are shown in Fig. 11. It is noticed that the QPSK system suffers almost the same amount of power penalty as DPSK system for lower values of jitter variance and at higher values of jitter; DPSK suffers more penalty than QPSK. For example, at a jitter variance of 0.2, the penalty at a BER of 10^{-8} is 9 dB for DPSK and 6 dB for QPSK.

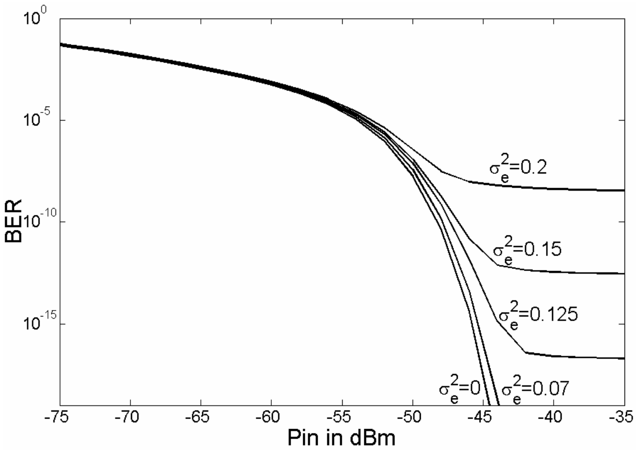

Fig. 9. BER vs. P_{in} (dBm) in presence of timing jitter for STBC-OFDM (QPSK) (N_s=16, F_d=60 Hz, σ_f^2 =0.1, T_s=10^{-6}s, T_x=4, R_x=1)

Fig. 12 presents the power penalty vs. timing jitter curve for OFDM and STBC-OFDM systems. This curve is plotted for QPSK modulation at a specific BER of 10^{-8}. From the figure, it can be concluded that jitter effect is less pronounced in STBC-OFDM than in stand alone OFDM system. For example, with QPSK modulation, at a jitter variance of 0.2, the penalty at a BER of 10^{-8} is 8.5 dB for OFDM and 6 dB for STBC-OFDM. From Table II, it is found that significant improvement of the BER performance is achieved by applying convolutional coding. Fig. 13 shows the effect of fading variance on the BER performance of QPSK OFDM system with one receiving antenna and four transmitting antennas. It is found that with decrease in fading variance there is degradation in system BER performance. Keeping jitter variance fixed to 0.1, we find that at fading variance σ_f^2 =0.25, the BER is 10^{-5} whereas at σ_f^2 =0.05, the BER increases to 10^{-3} at -60 dBm input power.

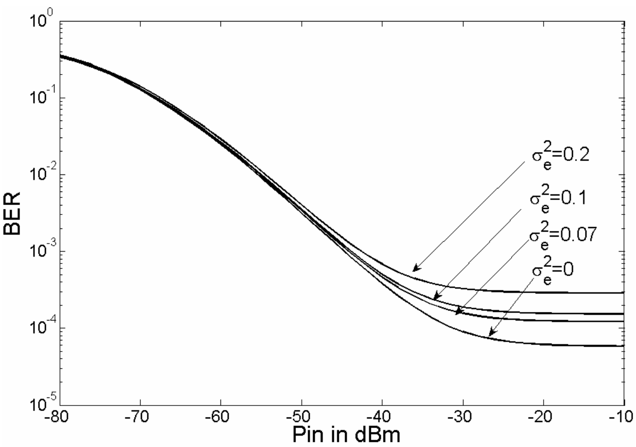

Fig. 8. BER vs. P_{in} (dBm) in presence of timing jitter for STBC-OFDM (DQPSK) (N_s=16, F_d=60 Hz, σ_f^2 =0.1, T_s=10^{-6}s, T_x=4, R_x=1)

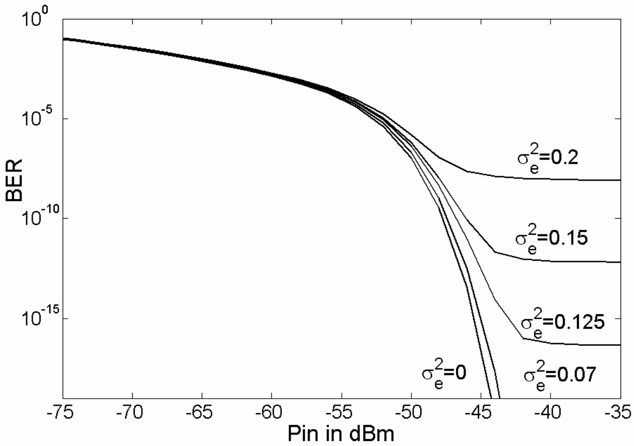

Fig. 10. BER vs. P_{in} (dBm) in presence of timing jitter for STBC-OFDM (DPSK) (N_s=16, F_d=60 Hz, σ_f^2 =0.1, T_s=10^{-6}s, T_x=4, R_x=1)

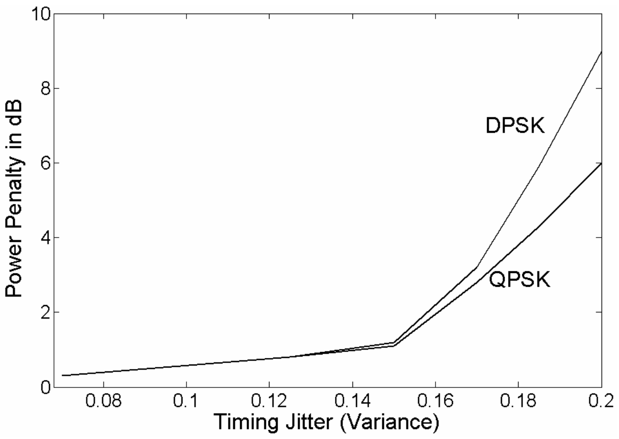

Fig. 11. Power Penalty vs. timing jitter with QPSK and DPSK modulation for STBC-OFDM at BER of 10^{-8}

TABLE II
BER Improvement due to coding for STBC-OFDM

Modulation	Pin (dBm)	Uncoded BER	BER (R=1/2 K=6)	BER (R=1/2 K=7)
QPSK	-40	10^{-9}	10^{-39}	10^{-46}
DPSK	-40	10^{-9}	10^{-37}	10^{-43}
DQPSK	-40	10^{-3}	10^{-13}	10^{-15}
DQPSK	-20	10^{-4}	10^{-14}	10^{-16}

Fig. 14 illustrates the performance comparison of STBC-OFDM with and without receiver diversity. The plots show that the BER reduces from 10^{-3} to 10^{-6} in presence of jitter σ_ε^2 =0.2 by deploying diversity combining in receiving side. It presents two pair of curves, in each pair, one curve is without jitter and another plot is with jitter.

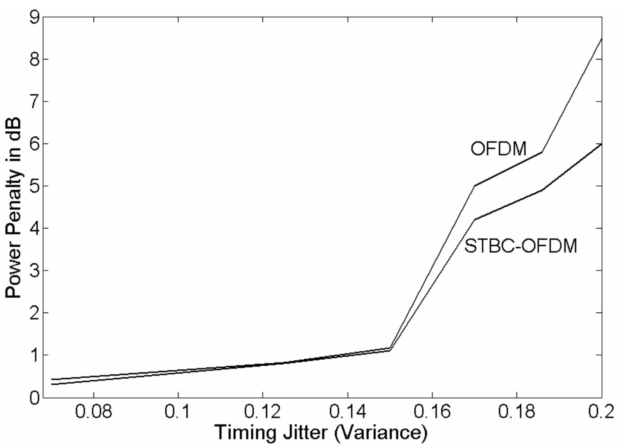

Fig. 12. Power Penalty due to timing jitter for OFDM and STBC-OFDM (QPSK) at BER of 10^{-8}

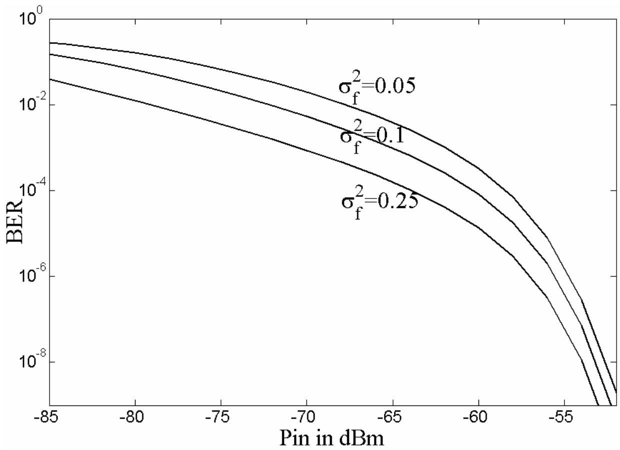

Fig. 13. BER vs. P_{in} (dBm) with variation in fading for STBC-OFDM (QPSK) (N_s=16, F_d=60 Hz, σ_c^2=0.1, T_s=10^{-6}s, T_x=4, R_x=1)

Fig. 15 shows the plots of space-time block coded MIMO-OFDM with DQPSK modulation system with and without convolutional coding in presence of timing jitter considering four transmitting and two receiving antennas. For convolution code of rate ½, the coding gain is 26 dB for constraint length K=6 and 28 dB for K=7 at an uncoded BER of 10^{-7}. It is also noticed that for higher amounts of input power, the coding gain is substantially higher in K=7 than in K=6. Fig. 16 shows the plots of BER vs. number of subcarriers (N_s) for different values of Doppler frequency normalized by symbol period. It is noticed that with the increase in Doppler frequency, the BER increases. From Fig. 16, it is also revealed that with increase in N_s, the BER decreases and becomes minimal and then increases for a particular value of Doppler frequency. It is observed that BER is minimal when number of subcarriers (N_s) is equal to 12.

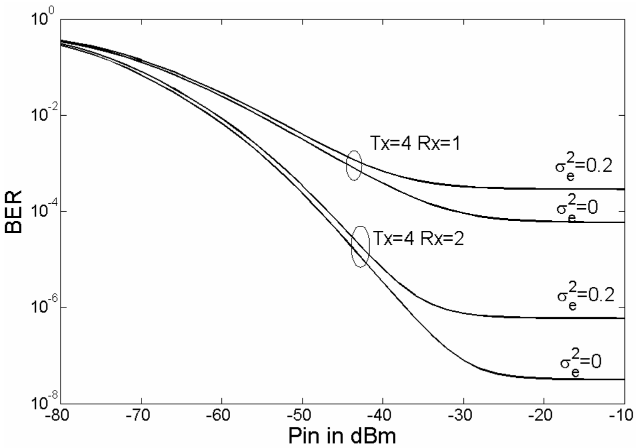

Fig. 14. Plots of BER vs. P_{in} (dBm) with & without receiving diversity for STBC-OFDM (DQPSK)

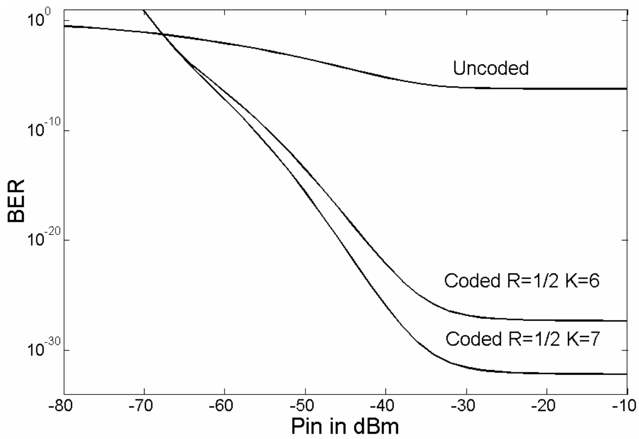

Fig. 15. BER vs. P_{in} (dBm) with and without coding for MIMO-OFDM (DQPSK) (N_s=16, F_d=60 Hz, σ_ε^2 =0.2, σ_f^2 =0.1, T_s=10^{-6}s, T_x=4, R_x=2)

Fig. 17 shows the plots of BER vs. P_{in} (dBm) for the analysis presented by Zhang in [9] and the proposed analysis of this paper. The plots are considered for Rayleigh channel with F_d=60 Hz, T_s=10^{-6}s, four number of transmitting and single receiving antennas. The proposed analysis shows more BER than the previous analysis presented by Zhang [9], because the proposed analysis considers additional impairments of timing jitter (σ_ε^2 =0.1) and channel attenuation (σ_f^2 =0.1). From the findings of the evaluation, we can propose an optimum system with following design parameters:

1. DQPSK as modulation scheme as it is more robust against jitter.
2. STBC-OFDM with T_x=4, R_x=2.
3. Number of OFDM subcarriers N_s =12.
4. Convolutional coding of rate ½ and K=7.

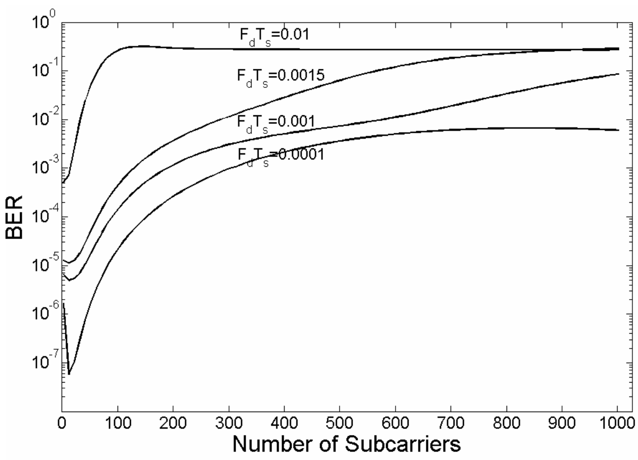

Fig. 16. BER vs. N_s (number of subcarriers) for MIMO-OFDM (DQPSK) (F_d=60 Hz, σ_ε^2 =0.01, σ_f^2 =0.1, T_s=10^{-6}s, T_x=4, R_x=2)

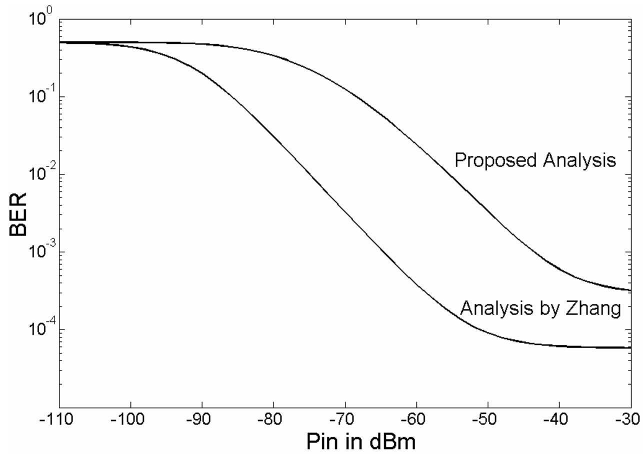

Fig. 17. BER vs. P_{in} (dBm) for previous and proposed analysis for STBC-OFDM (F_d=60 Hz, T_s=10^{-6}s, T_x=4, R_x=1)

V. Conclusion

We have analyzed the combined effects of timing jitter, time selective fading and AWGN on the BER performance of an OFDM system. For DQPSK, the jitter effect is less pronounced than coherently detected QPSK and DPSK. For example, at a jitter variance of 0.2, the penalty at a BER of 10^{-6} is 1.7 dB for DPSK, 1.5 dB for QPSK and 0.85 dB for DQPSK. It is also noticed that the QPSK system suffers almost the same amount of power penalty as DPSK system for lower values of jitter variance and at higher values of jitter; DPSK suffers more penalty than QPSK. For example, at a jitter variance of 0.2, the penalty at a BER of 10^{-8}, is 10.7 dB for DPSK and 8.5 dB for QPSK whereas at a jitter variance of 0.125, the penalty is 0.83 dB for DPSK and 0.80 dB for QPSK. We also observe that the BER of an OFDM system is much higher in Rayleigh fading channel than Rician channel. We compute the BER of OFDM in Rician fading channels with different Rician parameters and numerical results show that the performance is improved with higher values of Rician parameters. It is noticed that STBC-OFDM shows better BER performance than OFDM system. Numerical computations indicate that BER becomes higher with increase in Doppler frequency and increase in number of subcarirers. We extend the analysis for a MIMO-OFDM system with selection method for combining multiple receiving antennas and find substantial improvement in the system performance. As coded MIMO-OFDM successfully achieves outstanding performance, it can be used in practical applications where fading, jitter and AWGN strongly exist.

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