LOS and NLOS Performance of OFDM with PCC of ICI

Sherif Mamdouh Ziada
Research Scholar , Benha Faculty of Engineering , Benha University, Egypt
Dr. Abdel Aziz M. El-Bassiouni
Business Development Director TeleTech Company
Assoc. Prof. Ghada Mohamed Amer, Dr. Khalid Talaat Harb
Electrical Engineering Department, Benha Faculty of Engineering-Benha University

***Abstract*—Orthogonal frequency division multiplexing (OFDM) based wireless systems are spectrally efficient but they are vulnerable to Inter carrier interference (ICI). The rapid variation of the channel can induce ICI. ICI will significantly increase the difficulty of OFDM channel estimation. Polynomial Cancellation Coding (PCC) is a self-cancellation scheme proposed by Y. Zhao and S.G. Haggman [5]. PCC has CIR improvement of more than 15 dB compared to conventional OFDM [6]. It is shown that performance is improved as compared to conventional OFDM by about 4 dB in the QPSK modulation at an error rate of 10^{-2} over fading channels with a normalized carrier frequency offset of 0.1 . Exact BER calculation of BPSK Polynomial Cancellation Coding (PCC) of OFDM in multipath propagation of LOS and NLOS environment is evaluated for different normalized Carrier frequency Offset (CFO) values. In this treatment, the Rician K factor is used as a scale of the propagation environment ranging from perfect LOS no fading to Non LOS condition. In this paper shows that PCC-OFDM has 3 dB Eb/N0 performance improvement over conventional OFDM in CFO=0.1 and BER of 10^{-3} . In addition, since no channel equalization is needed for reducing ICI, the proposed scheme is therefore beneficial in implementation issue without increasing system complexity.**

Keywords- Orthogonal Frequency Division Multiplexing; Polynomial Cancellation Coding; Inter-carrier Interference; Interference Suppression, Rician Distribution K Factor

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a modulation technique of high spectral efficiency. Due to its reliability as wideband point-to-point (P2P) and point-to-multi-point (P2MP) transmission technique, OFDM is used as a backhaul to the high data rate 4G cellular base Stations and for serving gated compounds. OFDM is also used in the down link the 4G Long Term Evolution (LTE).

The performance degradation problem of OFDM due to frequency synchronization errors is considered in the literature [1-2]. Polynomial Cancellation Coding (PCC) is a self-cancellation scheme proposed by Y. Zhao and S.G. Haggman [5]. PCC has CIR improvement of more than 15 dB compared to conventional OFDM [6]. A closed form expression of the BER of BPSK conventional OFDM and PCC_OFDM subjected to Carrier Frequency Offset CFO over Nakagami-m Channel is evaluated in [3].

One of the Main advantages of OFDM is its resistance to multipath fading associated with urban areas. In such morphology, Line of Sight (LOS) propagation conditions is difficult to be achieved and Non Line of Sight (NLOS) propagation must be assumed. In NLOS multipath urban environment the received signal is composed of a dominant component and a scattered component. The Rician distribution describes the amplitude of the received signal. The Rician K Factor is defined as the ratio of the power of the dominant component and that of the scattered component. The case of K tending to zero corresponds to the Rayleigh channel and the case of K tending to infinity corresponds to the non fading channel. The Nakagami-m distribution describes the multipath propagation in which the received signal is the resultant of scattering components. The resulting Nakagami-m fading corresponds to the NLOS case.

The case of perfect LOS and the case of NLOS in which there is one dominant strong component in addition to the scattered components is not represented well by the Nakagami-m distribution. This case is best described by the Nakagami-n Distribution, also called the Nakagami-Rice Distribution or Rician Distribution. The Rician K-Factor is defined as the ratio of the dominant component power to the scattering component power. The Rician K-Factor is a suitable scale of the NLOS state.

In this paper, we deal with the problem of evaluating a BER expression of BPSK PCC-OFDM subjected to CFO in the multipath Rician fading Channel.The rest of the paper is organized as follows; in Section II, the analysis of CFO problem and PCC-OFDM is given. A closed form expression of the BER of BPSK PCC-OFDM is derived over a Nakagami-n (Rician) channel in Section III. Numerical results and discussion are included in Section IV. Finally, the conclusion is made in Section V.

II. CFO and PCC-OFDM ANALYSIS

For conventional OFDM, the receiver should decode the symbol $X(k)$ for the k_{th} SC, $k = 1,2,.....,N$. With the existence of CFO at the receiver, the FFT processed signal could be expressed as [4]:

$$Y(k) = X(k)S(1) + \sum_{l=1,l\neq k}^{N} X(l)S(l-k+1) + n(k) \quad ;k = 1,2,.....,N \quad (1)$$

Where, $X(k)$ is the transmitted symbol for the k_{th} SC, $n(k)$ is the additive white Gaussian noise of zero mean and variance σ^2 . Provided that the value of the CFO is ε , the ICI-coefficients $S(k)$ are given by [4]:

$$S(k) = \frac{\sin(\pi(k-1+\varepsilon))}{N\sin(\frac{\pi}{N}(k-1+\varepsilon))} \exp\left\{ j\pi(1-\frac{1}{N})(k-1+\varepsilon)\right\} \quad (2)$$

The above equations reveal the effects of CFO. The transmitted symbol $X(k)$ modulating the k_{th} SC is attenuated by $\sin(\pi(\varepsilon+1))/\{N\sin(\pi(\varepsilon+1)/N\}$ and its phase is rotated by $\exp\{j\pi(1-1/N)(\varepsilon+1)\}$. In addition, the transmitted symbol $X(k)$ is corrupted not only by the noise term, but also by the ICI represented by the second term in the right hand side of (1). Accordingly, system performance is degraded.

PCC-OFDM is introduced to reduce OFDM sensitivity to CFO. PCC-OFDM is a two step process [5]. At the transmitter, ICI cancelling modulation takes place through mapping data pair $(a,-a)$ onto adjacent SCs $l, l+1$. At the receiver, each signal at SC $k+1$ is multiplied by -1 and then summed with the one at the k_{th} SC. The resultant data sequence is used for making symbol decision.

Based on the above discussion, at the transmitter, data are mapped onto adjacent SCs according to:

$$X(2) = -X(1), X(4) = -X(3),....., X(N) = -X(N-1)$$

Now, the received signal on SC k can be expressed as:

$$Y'(k) = \sum_{l=1,l=odd}^{N-1} X(l)(S(l-k+1) - S(l-k+2)) + n(k) \quad (3)$$

And on SC $k+1$:

$$Y'(k+1) = \sum_{l=1,l=odd}^{N-1} X(l)(S(l-k) - S(l-k+1)) + n(k+1) \quad (4)$$

The receiver decision of the symbol $X(k)$ is based on [7]:

$$Y''(k) = Y'(k) - Y'(k+1) \quad (5)$$

$$Y''(k) = X(k)(2S(1) - S(0) - S(2)) + \sum_{l=1,l=odd;l\neq k}^{N-1} \begin{Bmatrix} X(l)(2S(l-k+1) \\ -S(l-k) \\ -S(l-k+2)) \end{Bmatrix} + (n(k) - n(k+1)) \quad (6)$$

It is apparent from (6) that the ICI coefficient is reduced, and the summation term includes odd values only. As a result, the CFO effect on performance is reduced.

III. BER of the DETECTION of BPSK for PCC-OFDM

This section considers the performance evaluation of BPSK modulated SCs when subjected to CFO, for both PCC-OFDM and conventional OFDM. The average error probability of PCC-OFDM when subjected to CFO over Nakagami-n fading channel is evaluated. Also, the average error probability for the conventional OFDM subjected to CFO over Nakagami-m fading channel is evaluated for sake of comparison.

For PCC-OFDM with BPSK modulated SCs, we assume $X(k) \in \{1,-1\}$ with equal probabilities. Without loss of generality, we consider only the first SC carries the symbol, $X(1) = 1$, and we find the error associated with the decision rule for this subcarrier.

a) The Conditional Probability of Error:

For BPSK, only the real part of (6) is the decision variable of X (k).

Now, define the matrix $E_{(N/2)-1}$ of dimension $(N/2)-1\times 2^{(N-2)-2}$ such that the k_{th} column of $E_{(N/2)-1}$ is the binary representation of the number $2^{(N-2)-1}-k$ where zeros are placed with -1. And define

$$\theta_k^{"} = R\left[2S(1)-S(0)-S(2)+S^{"T}e_k\right]$$
$$\beta_k^{"} = R\left[2S(1)-S(0)-S(2)-S^{"T}e_k\right] \quad (7)$$

Then, the corresponding error probability associated with the decision rule as $P_{be}=P\left\{RY^{"}(1)\langle 0\middle| X(1)=1\right\}$.The conditional BER, given some value of γ, can be expressed as:

$$P_{be}(\gamma)=\frac{1}{2^{\frac{N}{2}-1}}\sum_{k=1}^{2^{\frac{N}{2}-2}}\left[Q(\theta_k^{"}\sqrt{\gamma})+Q(\beta_k^{"}\sqrt{\gamma})\right] \quad (8)$$

Where: $\gamma=E_b/N_o$ and our case of interest is $E_b=1,\sigma^2=N_o/2$ with N_o is the noise spectral density.

For conventional OFDM with BPSK modulated SCs subjected to CFO, the conditional BER was developed in [(4, e q. 7)] As:

$$P_{be}(\gamma)=\frac{1}{2^{N-1}}\sum_{k=1}^{2^{N-2}}\left\{Q(\sqrt{2\gamma}\theta_k)+Q(\sqrt{2\gamma}\beta_k)\right\} \quad (9)$$

Where:

$$\theta_k = R\left[S(1)+S^T e_k\right] \ ,$$
$$\beta_k = R\left[S(1)-S^T e_k\right] \text{, and}$$
$$S=[S(2)S(3)....S(N)]^T \quad (10)$$

b) The Average Probability of Error over Rician fading Channel:

When subjected to Rician fading, the value of $\gamma=E_b/N_o$ will has a pdf given by [7- eq . 2.16]:

$$P_\gamma(\gamma)=\frac{(1+K)e^{-k}}{\bar{\gamma}}\exp\left[\frac{(1+K)\gamma}{\bar{\gamma}}\right]I_o\left[\frac{2\sqrt{K(1+K)\gamma}}{\bar{\gamma}}\right] \quad (11)$$

Where $\bar{\gamma}=E[\gamma]$ and K is the Rician K factor.

To obtain the average error probability in a Nakagami-n channel for PCC-OFDM with CFO, we evaluate:

$$P_{be\_PCC}=\frac{1}{2^{\frac{N}{2}-1}}\sum_{k=1}^{2^{\frac{N}{2}-2}}\left[\begin{array}{l}\int_0^\infty Q(\theta_k^{"}\sqrt{\gamma})P_\gamma(\gamma)d\gamma+\\ \int_0^\infty Q(\beta_k^{"}\sqrt{\gamma})P_\gamma(\gamma)d\gamma\end{array}\right] \quad (12)$$

By using the expression of the Gaussian Q function as given by [7-eq. 4.2]:

$$Q(x)=\frac{1}{\pi}\int_0^{\pi/2}\exp\left(\frac{-x^2}{2\sin^2(\theta)}\right)d\theta;x\rangle 0 \quad (13)$$

The Substitution of (13) into (12) will result in the moment generating function expression, and (11) will yield to:

$$P_{be}=\frac{1}{2^{\frac{N}{2}-1}\pi}\sum_{k=1}^{2^{\frac{N}{2}-2}}\left\{\begin{array}{l}\int_0^{\pi/2} M_\gamma\left(\frac{-\theta_k^{"2}}{2\sin^2\theta}\right)d\theta+\\ \int_0^{\pi/2} M_\gamma\left(\frac{-\beta_k^{"2}}{2\sin^2\theta}\right)d\theta\end{array}\right\} \quad (14)$$

Where $M_\gamma(-s)$ is the moment generating function expression which is defined in [7-eq. 5.13], and (12) yields:

$$P_{be\_PCC}=\frac{1}{2^{\frac{N}{2}-1}}\sum_{k=1}^{2^{\frac{N}{2}-2}}\left[\begin{array}{l}I(\theta_k^{"},K,\bar{\gamma})\\ +I(\beta_k^{"},K,\bar{\gamma})\end{array}\right] \quad (15)$$

Where,

$$I(a,K,\bar{\gamma})=\frac{(1+K)\sin^2(\theta)}{\frac{1}{\pi}\int_0^{\pi/2}(1+K)\sin^2(\theta)+a^2\bar{\gamma}/2}\exp\left[\frac{Ka^2\bar{\gamma}/2}{(1+K)\sin^2(\theta)+a^2\bar{\gamma}/2}\right]d\theta \quad (16)$$

Evaluation of the equation (15) for different values of K as $\overline{\gamma}$ varies will give the average probability of error of BPSK PCC-OFDM over Nakagami-n channel for different LOS and NLOS conditions. The BER of Conventional OFDM reception of BPSK can also be evaluated by averaging the conditional Probability of error given in (9) over the pdf of Eb/N0 γ given by (11). The result is given by:

$$P_{be\_Conventional\_OFDM} = \frac{1}{2^{(N-1)}} \sum_{k=1}^{2^{(N-2)}} \left[\mathrm{I}(\sqrt{2}\theta_k, K, \overline{\gamma}) + \mathrm{I}(\sqrt{2}\beta_k, K, \overline{\gamma}) \right] \quad (17)$$

Where θ_k and β_k are given by (10).

IV. NUMERICAL RESULTS and DISCUSSION

In this section, we provide a comparison of the results obtained for both PCC-OFDM and conventional OFDM subjected to CFO, over Nakagami-n (Rician) fading channels for different values of the Rician K factor. Figures (1), (2) and (3) show the BER of BPSK PCC-OFDM system subjected to CFO of values 0.1, 0.2 and 0.3 respectively. In the three figures, the K factors take values 0, 5, 10, 15, 20, 25 and ends at the Non-fading condition. The BER at K=0 represents the system performance in the Rayleigh channel. At the non-fading condition, the BER represents the perfect LOS behavior. Here only BPSK PCC-OFDM system technique is considered. We notice that as the value of k factor decreases, the BER increases. Figure (4) shows that PCC-OFDM has 3 dB Eb/N0 performance improvement over conventional OFDM in CFO=0.1 and BER of 0.001.

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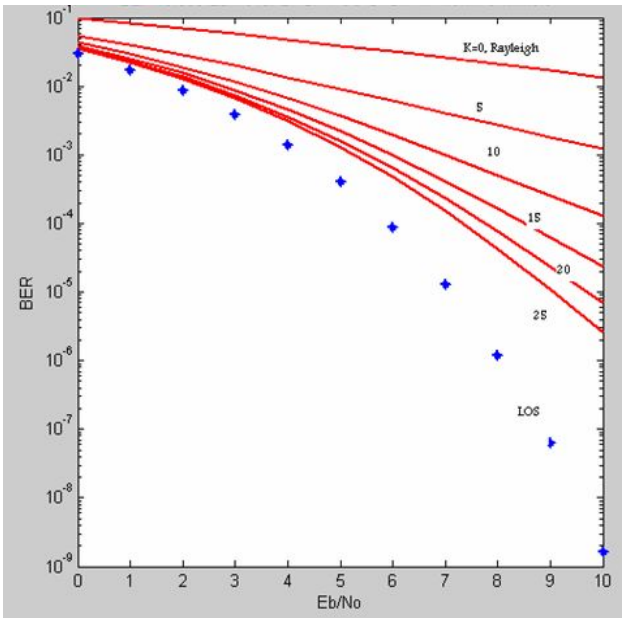

Figure 1: Performance of BPSK for OFDM System Utilizing Polynomial Cancellation Coding for CFO = 0.1 and for Different NLOS Conditions.

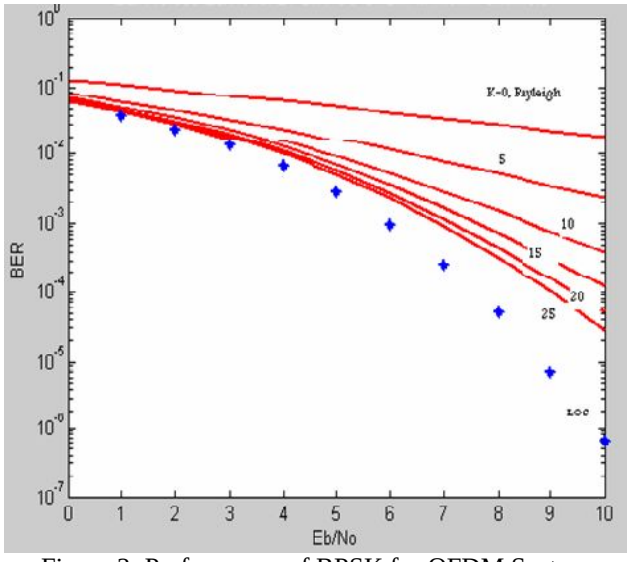

Figure 2: Performance of BPSK for OFDM System Utilizing Polynomial Cancellation Coding for CFO = 0.2 and for Different NLOS Conditions.

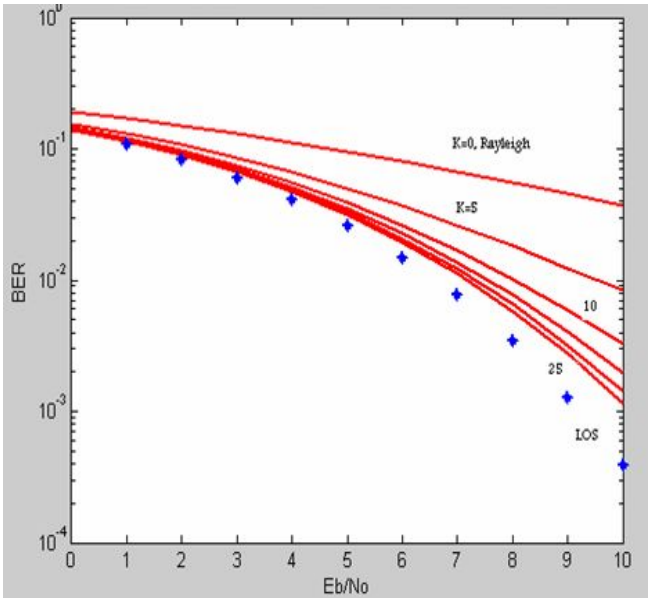

Figure 3:Performance of BPSK for OFDM System Utilizing Polynomial Cancellation Coding for CFO = 0.3 and for Different NLOS Conditions.

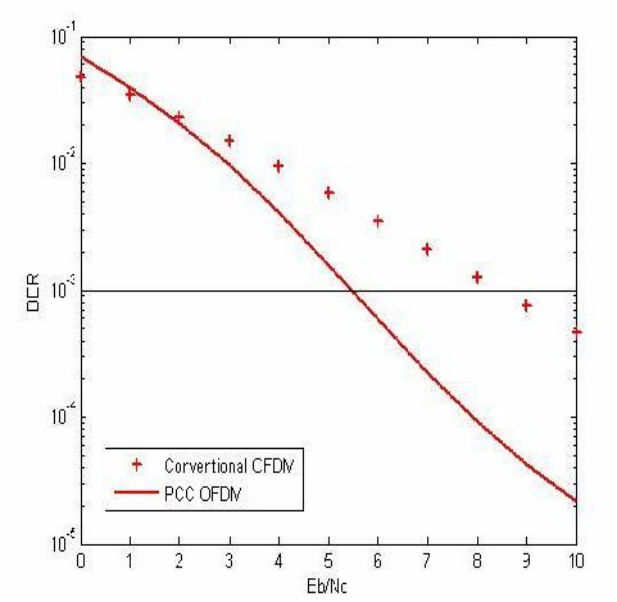

Figure 4: Performance Comparison of BPSK for OFDM Systems utilizing PCC and Conventional Method, for CFO = 0.1 and for Rician Fading of K=7.

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