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Performance Analysis of OFDM Based Cooperative Communication over Nakagami Fading Channel

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Abstract

Cooperative communication is a fourth generation novel scheme promising significant capacity and multiplexing gain in wireless communication. This paper derives the carrier to noise interference ratio (CNIR) and average bit error rate (BER) for orthogonal frequency division multiplexing (OFDM) based amplify and forward (AF) and decode and forward (DF) scheme over Nakagami fading channels. Numerical results are provided to show the significant improvement of DF in OFDM based cooperative communication due to same frequency offset and phase noise.

Keywords: *Amplify and forward, Decode and forward, Frequency offset, Orthogonal frequency division multiplexing and Nakagami fading*

1. Introduction

Cooperative communication is a capable key for the high data-rate exposure and enhanced capability with no physical antenna array in upcoming wireless communication scheme and it is likely to be a key enabling technology for efficient spectrum use in fourth generation (4G). 4G has two major benefits: cooperative relay scheme and combating the impairments of the wireless channel in this technology. The proposed schemes can increase the system reliability by achieving cooperative relay schemes and also increase their effective quality of service via cooperation.

Various relay schemes have been proposed to achieve the benefit such as amplify and forward (AF), decode and forward (DF), coded cooperation (CC) and Hybrid DF-AF relay scheme [1, 2]. The advantage of cooperative relay scheme is effortlessness and low cost implementation. Orthogonal frequency division multiplexing (OFDM) is a multiplexing technique and sensitive to normalized frequency offset and phase noise which obliterates the orthogonality among subcarriers and cause inter carrier interference (ICI). OFDM based on single relay cooperative transmission technique promises significant performance-gains in terms of link reliability, spectral efficiency, system capacity and transmission range. The Nakagami-*m* fading channel is commonly used to model the multipath fading radio transmission in urban areas, where the random fluctuations of the instant received signal power are very common and fast [3]. The benefits of Nakagami-*m* fading cover a wide range of multipath fading channels by varying its fading parameter m. It has greater flexibility in matching some experimental data than the Rayleigh, Rician fading [4, 5].

In this paper, we present without and with diversity expressions for carrier to noise interference ratio (CNIR) of OFDM based DF and AF relaying protocol with single number of relays that uses maximum ratio combining (MRC) technique at the destination for both cases. The average bit error rate (BER) expression has been derived for the proposed system with M-QAM modulation scheme in Nakagami fading channel. In

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addition, we have also evaluated the effect of frequency offset and phase noise in our proposed model.

2. System Model

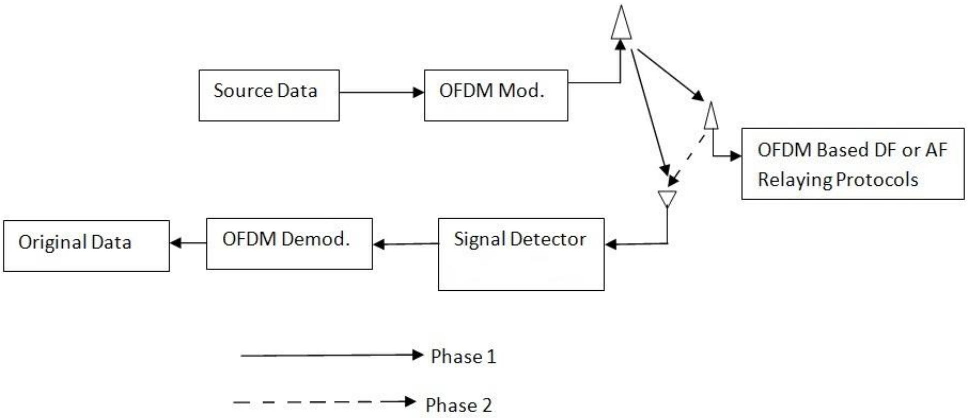

Figure 1. Diagram of OFDM based AF and DF Relaying Scheme

A basic OFDM based AF and DF relaying scheme is shown in Figure 1. In such OFDM based AF & DF relaying technique the source data are modulated into OFDM modulation. Then it simultaneously transmits information symbols. The outputs are subsequently sent into two ways in phase 1 and phase 2. In phase 1, the data transfer source to destination and source to relay directly. On the other hand, in phase 2 data transfer from relay to destination. In DF scheme, relay receives the information symbols and decodes the original message. Then it forwards the message to the destination. In the AF method, relay receives the information and then amplifies the signal. Finally, it transmits the amplified signal. One mobile acts as the source while the other mobile serves as the relay and the two mobiles may interchange their roles as source and relay anytime. In both cases, the relay enhances communication between the source and destination. At the reception side, each cooperative node has to forward its received signal through a wireless channel to the destination. In the destination section, the transmitted signals are detected with signal detection schemes and the detected signals are subsequently passed OFDM demodulator and decoded the original data.

3. Theoretical Analysis of Single Relay

3.1. Decode and Forward Relay Scheme

In DF relaying scheme, the relay at first decode the received signal then forwards the received signal to the destination. In Phase 1, the source-relay and the source-destination received signals are given by [6]

$$y_{k,s-r} = \sum_{l=0}^{N-1} x_{l,s} H_{l,s-r} Q_{l-k} + w_r$$

$$= x_{k,s} H_{k,s-r} Q_0 + I_{ICI}(s-r) + w_r \quad \textbf{(1)}$$

$$y_{k,s-d} = \sum_{l=0}^{N-1} x_{l,s} H_{l,s-d} Q_{l-k} + w_d^{(1)}$$

$$= x_{k,s} H_{k,s-d} Q_0 + I_{ICI}(s-d) + w_d^{(1)} \quad \textbf{(2)}$$

Where, $I_{ICI}(s-d) = \sum_{l=0, l\neq k}^{N-1} x_{l,s} H_{s-d,l} Q_{l-k}$ and

$I_{ICI}(s-r) = \sum_{l=0, l\neq k}^{N-1} x_{l,s} H_{s-r} Q_{l-k}$ are the inter carrier interference of the source to destination (s-d) and the source to relay (s-r). Here x_l , $H_{k,s-r}$ and $H_{k,s-d}$ are the transmitted information symbol, channel coefficients of the source to relay and the source to destination links respectively. The terms w_r ~CN $(0, \sigma_r^2)$ and $w_d^{(1)}$ ~CN $(0, \sigma_d^2)$ is the AWGN at the relay and the destination of phase 1 respectively. σ_r^2 and σ_d^2 are the relay and destination noise variance. ε is the normalized frequency offset and is given by *ΔfT*. *T* is the subcarrier symbol period.

Q_L is defined as follows

$$Q_L = \frac{1}{N}\sum_{n=0}^{N-1} e^{j[(\frac{2\pi}{N})(L+\varepsilon)n+\varphi(n)]} \quad \textbf{(3)}$$

In Phase 2, the received signal at the destination can be expressed as

$$y_{k,r-d} = \sum_{l=0}^{N-1} x_{l,r} H_{l,r-d} Q_{l-k} + w_d^{(2)}$$
$$= x_{k,r} H_{k,r-d} Q_0 + I_{ICI}(r-d) + w_d^{(2)} \quad \textbf{(4)}$$

Where $I_{ICI}(r-d) = \sum_{l=0, l\neq k}^{N-1} x_{l,r} H_{l,r-d} Q_{l-k}$ is the inter carrier inference of relay to destination, $|x_{k,r}|^2$ is the relay transmission power, $H_{k,r-d}$ is the channel coefficient of the relay to destination and $w_d^{(2)}$ is the AWGN at the destination of phase 2. The signals arriving at the destination can be combined by using with or without diversity technique. The carrier to noise interference ratio (CNIR) can be computed as

3.1.1. Condition 1:Without Diversity

In the condition of without diversity, the destination receives only the signal from relay. Using equation **(4)**, CNIR can be written as,

$$\gamma_{CNIR\_WOD} = \frac{\gamma_{r-d}|Q_0|^2}{1+\gamma_{r-d}\sum_{l=1}^{N-1}|Q_{l-k}|^2} \quad \textbf{(5)}$$

In the DF method, relay receives the source signal. Then it decodes the original message. So, we consider that $|x_{k,r}|^2 = |x_{k,s}|^2$ and $\gamma_{r-d} = \frac{|x_{k,s}|^2 |H_{k,r-d}|^2}{\sigma_d^2}$ is the carrier to noise ratio (CNR) from relay to destination. In the statistical properties **[7]**, assuming average channel gain

$$E[|H_{k,s-d}|^2] = E[|H_{k,s-r}|^2] = E[|H_{k,r-k}|^2] = 1 \text{ and } E[|x_{k,r}|^2] = |x|^2 \quad \textbf{(6)}$$

3.1.2. Condition 2: With Diversity

In with diversity combining, the signals received in Phases 1 and 2, *i.e.*, **(2)** and **(4)**, can be optimally combined at the destination with maximum ratio combining (MRC) to obtain the output signal is expressed as

$$y_{k,d_{WD\_DF}} = \frac{H^{*}_{k,s-d} Q_0}{P_{ICI}(s-d) + \sigma_d^2} y_{k,s-d} + \frac{H^{*}_{k,r-d} Q_0}{P_{ICI}(r-d) + \sigma_d^2} y_{k,r-d} \quad \textbf{(7)}$$

The effective average CNIR at the output of the OFDM based DF in MRC is given by

$$\gamma_{CNIR\_WD} = \frac{\gamma_{s-d}\left|Q_0\right|^2}{1 + \gamma_{s-d}\sum_{l=1}^{N-1}\left|Q_{l-k}\right|^2} + \frac{\gamma_{r-d}\left|Q_0\right|^2}{1 + \gamma_{r-d}\sum_{l=1}^{N-1}\left|Q_{l-k}\right|^2} \quad \textbf{(8)}$$

Where, $\gamma_{s-d} = \frac{\left|x_{k,s}\right|^2\left|H_{k,s-d}\right|^2}{\sigma_d^2}$ and $\gamma_{r-d} = \frac{\left|x_{k,s}\right|^2\left|H_{k,r-d}\right|^2}{\sigma_d^2}$ are the CNR from source to destination and relay to destination. For an OFDM based DF in Nakagami m-QAM fading Channel, the probability density function (pdf) of the instantaneous channel CNIR is given by **[8]**

$$p_\gamma(\gamma_{WOD})_{DF} = \left(\frac{m}{\gamma_{WOD}}\right)^m . \frac{\gamma_{WOD}^{m-1}}{\Gamma(m)} . e^{\left(-\frac{m\gamma_{WOD}}{\gamma_{WOD}}\right)}, \gamma \geq 0 \quad \textbf{(9)}$$

Where γ = average CNIR. The bit error rate (BER) of coherent M-QAM with two-dimensional Gray coding over the AWGN channel **[9]**

$$p_b(\gamma_{WOD})_{DF} \cong 0.2 e^{\left(\frac{-3\gamma_{WOD}}{2(M-1)}\right)} \quad \textbf{(10)}$$

The average BER in OFDM based DF Nakagami-*m* fading channel can be expressed as

$$p_b(\gamma_{WOD})_{DF} = \int_0^\infty p_b(\gamma_{WOD}) \times p_\gamma(\gamma_{WOD}) d\gamma$$

$$= 0.2\left(\frac{m}{\gamma_{WOD}\, v}\right)^m \quad \textbf{(11)}$$

Where $v = \frac{3\gamma_{WOD} + 2m(M-1)}{2(M-1)\gamma_{WOD}}$. The average BER expression is modified for the OFDM based DF with diversity over Nakagami-*m* fading channel. CNIR is used in eq. **(8)**.

3.2. Amplify and Forward Relay Scheme

In AF relaying scheme, the relay receives a signal from source then forwards the received signal to the destination in spite of the source-relay link quality. In Phase 1, the source-relay and the source-destination received signals are given by

$$y_{k,s-r} = \sum_{l=0}^{N-1} x_{l,s} H_{l,s-r} Q_{l-k} + w_r$$

$$= x_{k,s} H_{k,s-r} Q_0 + I_{ICI}(s-r) + w_r \quad \textbf{(12)}$$

$$y_{k,s-d} = \sum_{l=0}^{N-1} x_{l,s} H_{l,s-d} Q_{l-k} + w_d^{(1)}$$

$$= x_{k,s} H_{k,s-d} Q_0 + I_{ICI}(s-d) + w_d^{(1)} \quad \textbf{(13)}$$

In phase 2, the signal received by the relay that is attenuated and it is needed to be amplified before transmission another time. Assuming that the channel characteristic is estimated perfectly, the gain for the amplification can be calculated as follows. The desired received signal power is given by

$$E[|y_{k,r}|^2] = |x_{k,s}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2 \tag{14}$$

If the channel gain $|H_{k,s-r}|^2$ is known at the relay, the relay can multiply the received signal $y_{k,s-r}$ by the gain **[2]**,

$$\beta = \frac{1}{\sqrt{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2}} \tag{15}$$

The relay signal is found after multiplication of gain that is expressed by,

$$x_{k,r} = \beta \times y_{k,s-r} \tag{16}$$

The gain β depends on the source-relay channel coefficient $H_{k,s-r}$. The relay forwards the signal $x_{k,r}$ to the destination, where the received signal can be expressed as

$$\begin{aligned} y_{k,r-d} &= \sum_{l=0}^{N-1} x_{l,r} H_{l,r-d} Q_{l-k} + w_d^{(2)} \\ &= \sqrt{\frac{|x_{k,s}|^2}{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2}} H_{k,s-r} H_{k,r-d} |Q_0|^2 \\ &+ \frac{I_{ICI}(s-r)}{\sqrt{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2}} H_{k,r-d} Q_0 \\ &+ \frac{1}{\sqrt{|x_{k,s}|^2 |H_{k,s-r}|^2 Q^2 + P_{ICI}(s-r) + \sigma_r^2}} H_{k,r-d} Q_0 w_r \\ &+ I_{ICI}(r-d) + w_d^{(2)} \end{aligned} \tag{17}$$

The signals arriving at the destination can be exploited for recognition with or without diversity combining.

3.2.1. Condition 1:Without Diversity

In the condition without diversity combining, only the signal $y_{k,r-d}$ will be utilized for detection at the destination. By (17), the received CNIR in this case can be computed as

$$\gamma_{CNIR\_WOD} = \frac{\gamma_{s-r}\gamma_{r-d}|Q_0|^4}{1 + \gamma_{s-r}[|Q_0|^2 + \sum_{l=1}^{N-1}|Q_{l-k}|^2] + \gamma_{r-d}[|Q_0|^2 + \sum_{l=1}^{N-1}|Q_{l-k}|^2] + \gamma_{s-r}\gamma_{r-d}[2\sum_{l=1}^{N-1}|Q_0|^2|Q_{l-k}|^2 + 2\sum_{l=1}^{N-1}|Q_{l-k}|^2]} \tag{18}$$

3.2.2. Condition 2: With Diversity

In the condition with diversity combining, the signals received in (13) and (17), can be optimally combined at the destination employing maximum ratio combining (MRC) to obtain the output signal is expressed as,

$$y_{k,d} = \frac{H^{*}_{k,s-d} Q_0}{P_{ICI}(s-d) + \sigma_d^2} y_{k,s-d} + \frac{\sqrt{\frac{1}{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2}} H^{*}_{k,s-r} H^{*}_{k,r-d} |Q_0|^2}{\frac{P_{ICI}(s-r)}{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2} |H_{k,r-d}|^2 |Q_0|^2 + \frac{1}{|x_{k,s}|^2 |H_{k,s-r}|^2 |Q_0|^2 + P_{ICI}(s-r) + \sigma_r^2} |H_{k,r-d}|^2 |Q_0|^2 \sigma_r^2 + P_{ICI}(r-d) + \sigma_d^2} y_{k,r-d} \quad \textbf{(19)}$$

The effective CNIR of OFDM AF with diversity combining at the output of the MRC is given by

$$\gamma_{CNIR\_WD} = \frac{\gamma_{s-d} |Q_0|^2}{1 + \gamma_{s-d} \sum_{l=1}^{N-1} |Q_{l-k}|^2} + \frac{\gamma_{s-r}\gamma_{r-d} |Q_0|^2}{1 + \gamma_{s-r}[|Q_0|^2 + \sum_{l=1}^{N-1} |Q_{l-k}|^2] + \gamma_{r-d}[|Q_0| + \sum_{l=1}^{N-1} |Q_{l-k}|^2] + \gamma_{s-r}\gamma_{r-d}[|Q_0| \sum_{l=1}^{N-1} |Q_{l-k}|^2 + |Q_0|^2 \sum_{l=1}^{N-1} |Q_{l-k}|^2 + 2 \sum_{l=1}^{N-1} |Q_{l-k}|^2]} \quad \textbf{(20)}$$

Whereas, $\gamma_{s-d} = \frac{|x_{k,s}|^2 |H_{k,s-d}|^2}{\sigma_d^2}$ and $\gamma_{r-d} = \frac{|x_{k,s}|^2 |H_{k,r-d}|^2}{\sigma_d^2}$ are the CNR from source to destination and relay to destination. The average BER in OFDM based AF Nakagami-m fading channel can be expressed as

$$p_b(\gamma_{WOD})_{AF} = \int_0^\infty p_b(\gamma_{WOD}) \times p_\gamma(\gamma_{WOD}) d\gamma$$

$$= 0.2 \left(\frac{m}{\gamma_{WOD} \, v} \right)^m \quad \textbf{(21)}$$

Where, $v = \frac{3\gamma_{WOD} + 2m(M-1)}{2(M-1)\gamma_{WOD}}$. The average BER expression is modified for the OFDM based AF with diversity over Nakagami-m fading channel. CNIR is used in eq. **(20)**.

4. Results & Discussion

In this section, we discuss the simulation results of both without and with diversity technique in single relay cooperative communication. We focus on the CNIR and average BER performance analysis of both an AF & DF relay schemes. The normalized frequency offset and phase noise is set to be 0.05 and 0.025 respectively. The M-ary, subcarrier, number of IFFT and FFT are taken to be 4, 64, 64 and 64 respectively.

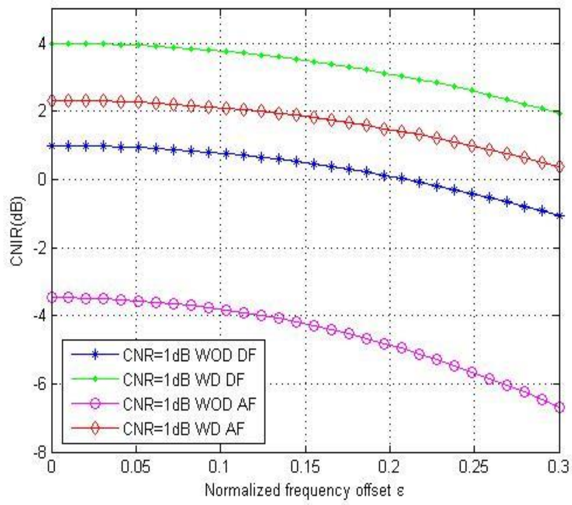

Figure 2. Plots of CNIR (dB) vs. Normalized Frequency Offset

The effect of normalized frequency offset is shown in Figure 2. It also shows a performance analysis of the cooperative communication system with implementation of DF and AF relaying protocol under without and with diversity technique. The system provides a quite satisfactory performance of CNR = 1dB WD DF relay scheme. For a typically assumed that normalized frequency offset ε value of 0.2, the CNIR values are approximately -4.808, 0.1268, 1.502 and 3.137 in the case of without and with diversity for AF and DF method. The performance of the system is improved in CNR = 1dB WD DF by approximately 3.20 dB as compared to the CNR = 1dB WD AF respectively.

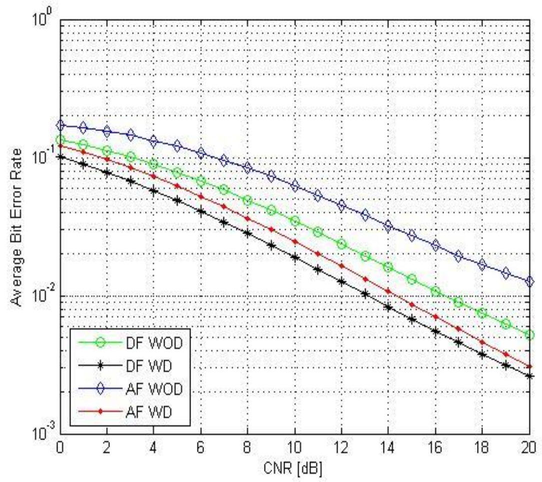

Figure 3. Average Bit Error Rate vs. CNR

Figure 3 shows the comparison between OFDM based cooperative DF and AF relay scheme for the Nakagami fading parameter, $m = 1$. It is also noticed that the CNR value increases, performance has less average bit error rate to all schemes. The values of average bit error rate of AF WD, AF WOD, DF WD and DF WOD are approximately 0.03627, 0.08369, 0.02807 and 0.04923 respectively at CNR=8 dB.

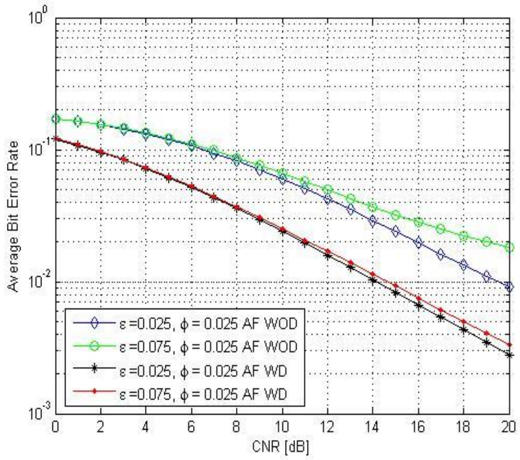

Figure 4. Effects of Frequency Offset on Average BER in AF Scheme

The effects of frequency offset on average bit error rate with different CNR are plotted in Figure 4. It is observed that AF relay scheme with diversity has better performance than that of without diversity. Average BER decreases with increasing CNR and also for a particular CNR value, average BER increases as the frequency offset increases. For instance, at $\varepsilon = 0.025$ AF WD, AF WOD and $\varepsilon = 0.075$ AF WD, AF WOD in OFDM based cooperative AF relay scheme value of average BER approximately are 0.01584, 0.04233 and 0.01693, 0.04932 when CNR value of 12 dB. The scheme performance is increased in $\varepsilon = 0.025$ AF WD by approximately 4.26 dB as compared to AF WOD.

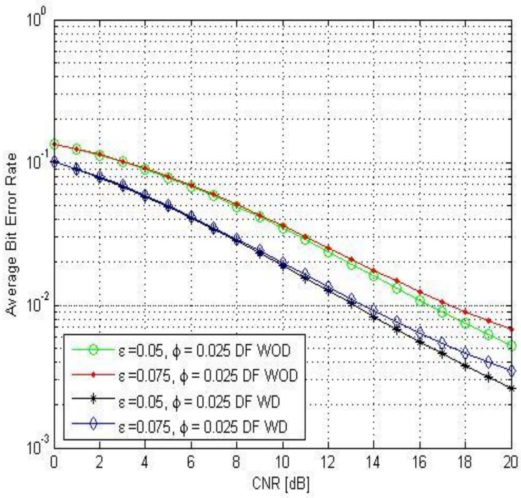

Figure 5. Effects of Frequency Offset on Average BER vs. CNR in DF Scheme

Figure 5 shows the performance analysis of average BER vs. CNR in DF relay scheme. DF with lower frequency offset is better than higher frequency offset. For a typically assumed CNR value of 10 dB, the average BER values are approximately 0.02807, 0.04923, 0.02893 and 0.05055 in the case of $\varepsilon = 0.05$ DF WD, DF WOD and $\varepsilon = 0.075$ DF WD, DF WOD scheme. It is observable that at very high CNR, the various relay schemes performance is comparatively better under deployment of the OFDM based cooperative DF relay scheme. However, the best performance is that of the $\varepsilon = 0.05, \phi = 0.025$ $DF\ WD$ relay scheme.

5. Conclusions

The paper presents performance analysis for OFDM based cooperative communication without and with diversity technique over Nakagami fading channels. Some analytical expression for the CNR, CNIR and average BER of DF and AF scheme are obtained. Our numerical results show that the overall performance of the cooperative DF relay scheme in presence of frequency offset and phase noise is slightly better in contrast to the performance of AF relay scheme.

References

[1] H. Li, H. Nikookar and T. Xu, "OFDM Communications with Cooperative Relays", Communications and Networking Book, **(2010)**.

[2] Y. W. Peter Hong, H. Wan-Jen and C. C. Jay Kuo, "Cooperative Communications and Networking", Technologies and System Design, Springer Science and Business Media, LLC, New York, ISBN-10: 1441971939, **(2010)**.

[3] C. Chunxiao, Y. Wendong and C. Yueming, "Outage performance of OFDM-based selective decode-and forward cooperative networks over weibull fading channels", High Technology Letters, vol. 17, no. 3, **(1995)**, pp. 285-289.

[4] N. C. Beaulieu and C. Cheng, "An efficient procedure for Nakagami-m fading simulation", IEEE Global Telecommunications Conference, vol. 6, **(2001)**, pp. 3336-3342.

[5] J. Luo, J. Zeidler and S. McLaughlin, "Performance analysis of compact antenna arrays with MRC in correlated Nakagami fading channels", IEEE Trans. Veh. Technol., vol. 50, no. 1, **(2001)**, pp. 267-277.

[6] Y.-S. Li, H.-G. Ryu, J.-W. Li, D.-Y. Sun, H.-Y. Liu, L. –J. Zhou and Y. Wu, "ICI compensation in MISO-OFDM system affected by frequency offset and phase noise", Wireless Commun., Networking and Mobile Computing (WiCOM '08), vol. 5, no. 12, **(2008)**, pp. 32-38.

[7] V. K. Dwivedi and G. Singh, "An efficient BER analysis of OFDM systems with ICI conjugate cancellation method", PIERS Proceedings, Cambridge, USA, **(2008)**.

[8] M. S. Alouini and A. J. Goldsmith, "Adaptive modulation over Nakagami fading channels", Wireless Personal Communications: An International Journal, vol. 13, no. 1-2, **(2000)**, pp. 119-143.

[9] T. Quazi and H. Xu "Performance analysis of adaptive M-QAM over a flat-flading Nakagami-m channel", S Afr J Sci., **(2011)**.