Phase Noise Effects in Synchronized Wireless Networks for MIMO-OFDM

MUHAMMAD KHURRAM KIYANI*, AND ASIM LOAN*

RECEIVED ON 08.11.2012 ACCEPTED ON 09.01.2014

ABSTRACT

Channel impairments effects are evaluated by inclusion of phase noise in a synchronization error correction algorithm for MIMO (Multiple Input Multiple Output) OFDM (Orthogonal Frequency Division Multiplexing) systems. The original synchronization error correction algorithm applicable to AWGN (Additive White Gaussian Noise) channel pertaining to SISO (Single Input Single Output) system is modified in the presence of SUI (Stanford University Interim) channel models and then applied to MIMO systems. Then the performance of this modified algorithm is verified through simulations under the effects of channel impairments.

Key Words: **Synchronization, Channel Impairments, Orthogonal Frequency Division Multiplexing, Additive White Gaussian Noise Channels, Stanford University Interim Channels.**

1. INTRODUCTION

MIMO-OFDM systems are gaining popularity and are rapidly shifting towards commercialization. Endeavors have already been in vogue by various researchers to analyze MIMO-OFDM systems in the presence of phase noise. In Bittner, et. al. [1] problem of phase noise harmonics is addressed using only MIMO systems and OFDM was not incorporated in it. Rabiei, et. al. [2] estimated the channel impulse response in the presence of channel impairments using maximum likelihood estimation for MIMO-OFDM systems. Zhang, et. al. [3], analyzed the MIMO-OFDM systems are analyzed to cater phase noise in fading channels but they did incorporate frequency offset estimation and correction as is the case in this paper. In another work, Jiang, et. al. [4], channel impairment effect is analyzed by using the PN statistics of iterative receivers for MIMO-OFDM system. In addition to that, Corvaja, et. al. [5], analyzed a MIMO OFDM system having imperfect channel estimation for channel impairment effects. Mehrpouyan, et. al. [6] carriedout the joint estimation of channel and phase noise, however, OFDM was not incorporated. Moreover, Tailor, et. al. [7] have thoroughly discussed different channel impairments which includes the phase noise but the effects of phase noise in the presence of synchronization errors are not explored. Apropos from above the area of channel impairment in MIMO-OFDM having synchronization errors is less explored. This paper is an extension and verification of authors' earlier work specific to synchronization [8], by taking a step ahead and testing the authenticity of

* Assistant Professor, Department of Electrical Engineering, University of Engineering & Technology, Lahore.

proposed modified algorithm by adding different values of phase noise in it.

The rest of the paper is divided into various sections in which Section 2 encompasses modular details and Section 3 describes the modalities of modified algorithm. Section 4 exhibits the simulative description of the effects of different values of phase noise on modified algorithm and Section 5 concludes the description. Moreover in this paper symbol "I" represents the Identity matrix, symbol "." represents dot product and symbol "⊗" represents kronecker product.

2. MODULAR DESCRIPTION

2.1 Background

Major causes of introduction of frequency offset in any system are Doppler Effect and instability of the LO (Local Oscillator). Phase noise is also the result of lack of capability of LO to produce a single frequency accurately. These impairments and inaccuracies severely degrade the performance of any system and the effect is more pronounced for MIMO-OFDM systems as they are more sensitive to these effects. Hence these inaccuracies/ offsets have to be addressed properly to enhance the performance of the system.

2.2 SUI Channels

A realistic channel is always random and most of the time quasi static multipath . Therefore, the transmitting sequence follows a burst pattern where burst length adheres to channel coherence time. In this paper SUI 1 and SUI 3 channels [9] have been used for transmission of a burst or packet.

2.3 Transmission Pattern

A preamble has to be used in every packet for better estimation and correction. In this paper the preamble mentioned in IEEE 802.16 10] and IEEE 802.1. 1n [11] is used in every burst. Generally there are number of transmission strategies which are used for sending data in MIMO System (Fig. 1). This paper has exploited orthogonality in time domain by sending data from only antenna at one time.

3. ALGORITHM DETAILS

The preamble vector used as a training sequence by WLAN and WMAN is denoted by "V(p)". This frequency domain preamble vector is converted into time domain vector "T(p)" by a mathematical operation[10] i.e.

$$T(p) = \left(F^{-1} \otimes I_N\right) \bullet V(p) \tag{1}$$

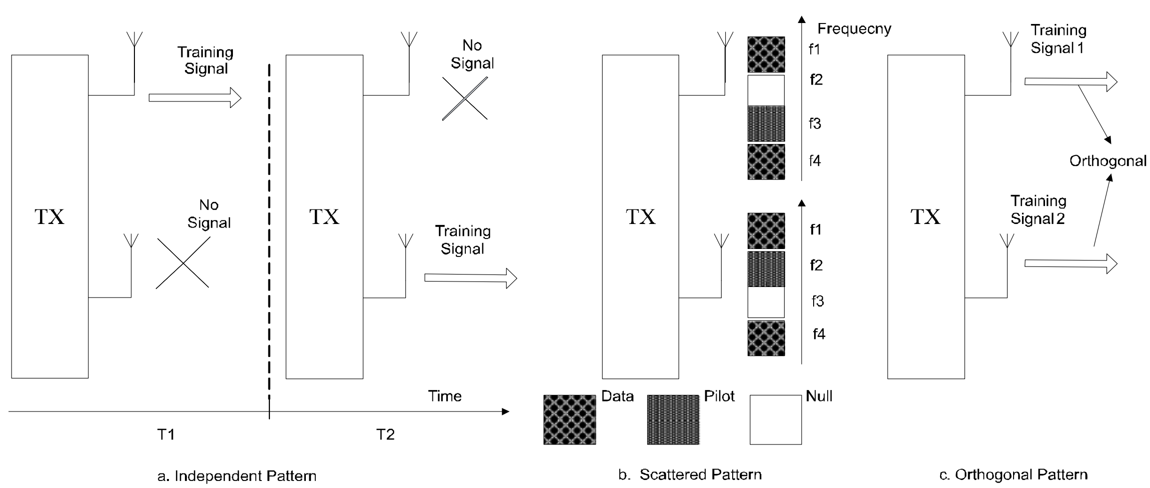

FIG. 1. TRANSMISSION STRATEGIES FOR SENDING DATA IN MIMO SYSTEMS [12]

where F^{-1} is Inverse Discrete Fourier Transform and subscript "N" are the total number of subcarriers in a symbol. A cyclic prefix "g" in accordance with the coherence time of the channel is appended to the preamble to make it ready as a signal "S(p)"to be transmitted i.e.

$$S(p) = g\left\{\left(F^{-1} \otimes I_N\right) \bullet V(p)\right\} \tag{2}$$

The signal "S(p)" is then transmitted from transmitter side and after traversing the channel it is received at the receiver as "R(p)" such as:

$$R(p) = H\left[g\left\{\left(F^{-1} \otimes I_N\right) \bullet V(p)\right\}\right] + B(p) \tag{3}$$

Here "H" is the channel matrix and "B(p)" denotes the total noise added to the system. The cyclic prefix appended to the preamble before transmission is removed and the index "p" inside the parenthesis is omitted for better understanding. The received signal then becomes:

$$r = g^{-1}R = H\left[g^{-1}g\left\{\left(F^{-1} \otimes I_N\right)V\right)\right\}\right] + B \tag{4}$$

This received signal is then converted to frequency domain by performing Discrete Fourier transform i.e.

$$r = \left(F^{-1} \otimes I_N\right)H\left\{\left(F^{-1} \otimes I_N\right)V\right\} + B \tag{5}$$

The received signal "r" for a particular subcarrier "a" can be written as:

$$r(a) = h(a)se^{j[2\pi f(a)t + \phi(a)]} + b(a), \forall 1 \le a \le N \tag{6}$$

where "h (a)" is the time domain response of a channel for that particular subcarrier, "f(a)" is the frequency offset and "φ(a)" is the unknown phase noise whose different values will be added in the modified algorithm to check the robustness and range of the algorithm. "b(a)" is additive white Gaussian noise with zero mean and variance "σ^2".

Since the modulation used by preamble symbols of WMAN and WLAN is Phase Shift Keying as given in [10] and [11] so data symbol "s" is neutralized by its conjugate and Equation (6) is modified as:

$$r(a) = h(a)e^{j[2\pi f(a)t + \phi(t)]} + b(a) \tag{7}$$

Now if "r(a)" is auto correlated, "h(a)" is neutralized by normalizing i.e. $|h(a)|^2$ and the new equation becomes:

$$r(a) = e^{j2\pi f(a)t} + \eta(a) \tag{8}$$

where "η(a)" is the noise figures after autocorrelation.

Here the following identity has been used:

$$\sum_{m=1}^{N} e^{j2\pi m v T} = \frac{\sin \pi N v T}{\sin \pi V T} e^{j\pi(N+1)vT} \tag{9}$$

If the sine ratio term is positive we can extract an estimate of v using argument of the complex number. $\sin(\pi NvT)/\sin(\pi VT)$ is positive for $|v| \le 1/(NT)$, so that sets an upper limit on the maximum frequency offset the algorithm can correct. Assuming that the frequency offset is within the desired range, the algorithm at [13] can be applied to get the estimation of synchronization error i.e.

$$\hat{f} = \frac{1}{\pi(N+1)t} \arg\left\{\sum_{a=1}^{N} r(a)\right\} \tag{10}$$

Moreover, the cross correlation proposed in [8] by the authors further improves the results. However, this paper largely focuses on the phase noise effects on the proposed algorithm at [8] and has used different values of phase noise in simulations to show the validity of the proposed algorithm. Therefore, the next section is dedicated to various results obtained through simulations after adding different values of phase noise in this algorithm.

4. SIMULATIVE ANALYSIS

Fig. 2 show the performance of modified algorithm [8] vis a vis original algorithm in [13] in the presence of phase noise for WLAN. Results related to WLAN are presented as under:

4.1 Phase Noise = -80dBc/Hz=0.11 Degrees

In Fig. 2 a comparison of both the original and modified algorithm is shown. This comparison is different from the authors' previous work at [8] as these results are obtained under the effect of phase noise. Simulation results clearly manifest the authenticity of modified algorithm in the presence of phase noise of -80dBc/hz.

4.2 Phase Noise = -100dBc/Hz=0.011 Degrees

For the phase noise of -100dBc/hz the curves shown in Fig. 3 show the superiority of the modified algorithm validating the results of [8].

4.3 Phase Noise=-120dBc/Hz=0.0011 Degrees

In Figs. 2-4 a performance comparison between original and modified algorithm is presented in the presence of phase noise. Now a step further is taken to categorically view the effects of phase noise on modified algorithm only. In order to achieve that, simulations were again carried out for modified algorithm in the presence and absence of phase noise. Figs. 5-6 show the result of the simulations for WLAN models only.

In Fig. 5 phase noise of 0.01 degrees was added but the results are inferior in performance as compared to absence of phase noise. In order to check the effect of smaller values of phase noise as well a phase noise of 0.001 degrees is added and then the results are shown in Fig. 6.

Figs. 5-6 have clearly shown that the performance of proposed algorithm gets deteriorated by a factor 0.001 in terms of Mean Square Error once phase noise is added to the system. This result is fair testimony to the fact that MIMO-OFDM systems are very sensitive to channel impairments and even smaller value of phase noise has brought a significant degradation in the system performance.

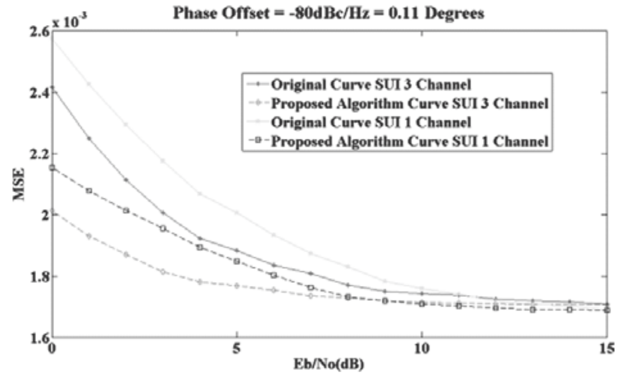

FIG. 2. COMPARISON OF ORIGINAL AND MODIFIED ALGORITHM FOR 0.11 DEGREES

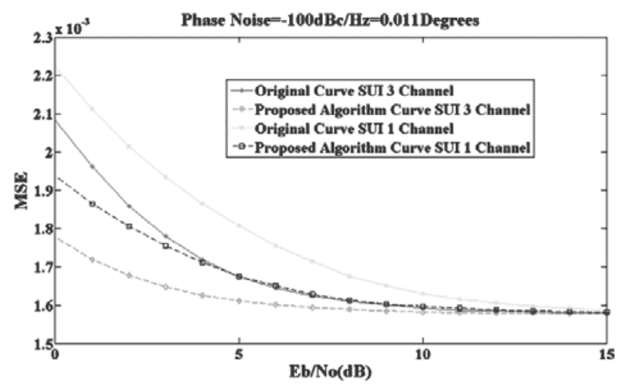

FIG. 3. COMPARISON OF ORIGINAL AND MODIFIED ALGORITHM FOR 0.011 DEGREES

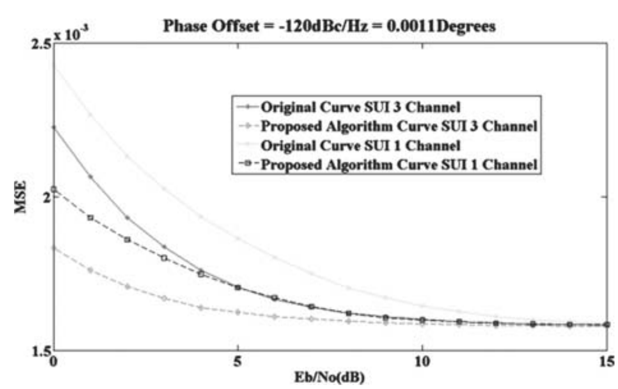

FIG. 4. COMPARISON OF ORIGINAL AND MODIFIED ALGORITHM FOR 0.0011 DEGREES

5. FUTURE RECOMMENDATIONS

This paper shows a lot of scope and potential in its extension and expansion for future work. The major areas for improvement and extension of the work in this paper are as under:

(a) Channels used in this paper are SUI channels and the whole model of system revolves around these specific channels. In future endeavors other realistic channels can be incorporated in the system to view the performance of the proposed algorithm.

(b) Only two transmit antennas and their preamble have been used for auto and cross correlation in this paper. However the next work may be extended to more than two antennas and then the analysis of the whole system is to be carried out in terms of its advantages and disadvantages.

(c) For transmission, orthogonality in time domain is achieved by transmitting the preamble from one antenna at one time as shown in Fig. 1(a). Future work should also explore the viability of other transmission strategies.

(d) Bit Error Rates of the proposed algorithm can also be investigated using monte carlo simulations to obtain a better picture of the robustness of the proposed algorithm for different values of phase noise.

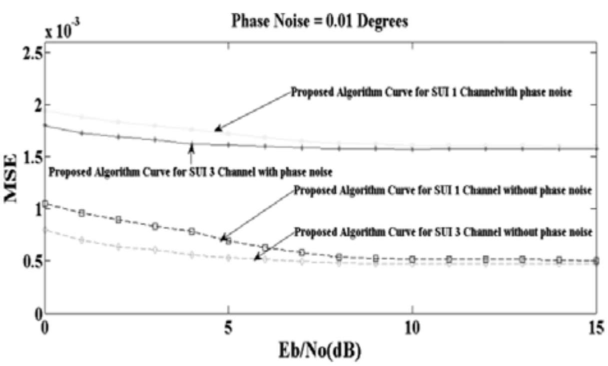

FIG. 5. PERFORMANCE COMPARISON OF MODIFIED ALGORITHM WITH AND WITHOUT PHASE NOISE

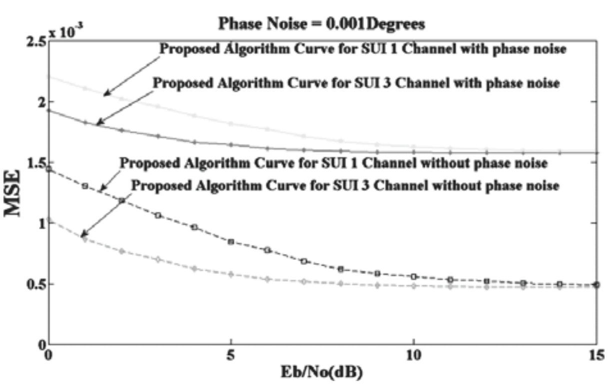

FIG. 6. MODIFIED ALGORITHM IN THE PRESENCE AND ABSENCE OF PHASE NOISE

5. CONCLUSION

The effects of phase noise have been exhaustively studied in different environments of MIMO-OFDM systems using the proposed modified algorithm. In comparison to the original algorithm, the proposed algorithm has shown robustness and proved its viable authenticity under different values of phase noise. It clearly portrays that the proposed modified algorithm remained superior in performance even in the presence of channel impairments such as phase noise. However, once the modified algorithm has been analyzed with and without the phase noise, the performance of the algorithm is superior in the absence of phase noise as expected.

ACKNOWLEDGEMENT

The authors would like to acknowledge Higher Education Commission (HEC) Pakistan for providing the financial support and necessary guidance in making this research fruitful and productive.

REFERENCES

[1] Bittner, S., Rave, W., and Fettweis, G., "Phase Noise Suppression in OFDM with Spatial Multiplexing", 1st Project IST-4-027756 WINNER-II.

[2] Rabiei, P., Namgoong, W., and Al-Dhahir, N., "Reduced-Complexity Joint Baseband Compensation of Phase Noise and I/Q Imbalance", IEEE Globecom, Hawaii, USA, December, 2009.

[3] Zhang, Y., and Huaping L., "MIMO-OFDM Systems in the Presence of Phase Noise and Doubly Selective Fading", IEEE Transactions on Vehicular Technology, Volume 56, No. 4, pp. 2277-2285, July, 2007.

[4] Jiang, Y., Xiao, X.G., and Minn, H., "Performance Analysis of Iterative MIMO OFDM Receivers under the Presence of Phase Noise", 67th IEEE Vehicular Technology Conference, VTC Spring, 11-14 May, 2008.

[5] Corvaja, R., and Armada, A.G., "Effect of Channel Estimation Errors in MIMO OFDM Systems with Phase Noise Compensation", IEEE Globecom, LA, USA, December, 2008.

[6] Mehrpouyan, H., Nasir, A.A., Blostein, S.D., Eriksson, T., Karagiannidis, G.K., and Svensson, T., "Joint Estimation of Channel and Oscillator Phase Noise in MIMO Systems", IEEE Transactions on Signal Processing, Volume 60, No. 9, September, 2012.

[7] Tailor, K.H., and Shah, S.N., "A Review on Various Interference Effects in a MIMO-OFDM System", International Journal of Engineering Research and Technology, Volume 2, No. 1, January, 2013.

[8] Kiyani, M.K., Ahmed, M.U., and Loan, A., "Synchronization in Wireless Networks for Practical MIMO OFDM Systems", International Journal of Communications, Network and System Sciences, Volume 3, No. 5, pp. 483-487, May, 2010.

[9] Erceg, V., Hari, K.V.S., Smith, M.S., and Baum, D.S., "Channel Models for Fixed Wireless Applications", IEEE802.16.3 Task Group Contributions, 1st February, 2001.

[10] "IEEE Standard for Local and Metropolitan Area Networks-Air Interface for Fixed Broadband Wireless Access Systems", IEEE Wireless MAN 802.16, 24 June, 2004.

[11] "IEEE P802.11n/D11.0 Draft Standard for Information Technology, Telecommunications and Information Exchange between Systems-Local and Metropolitan Area Networks Part-11", Wireless LAN Medium Access Control and Physical Layer Specifications, 2009.

[12] Andrews, J.G., Ghosh, A., and Muhamed, R., "Fundamentals of WiMAX Understanding Broadband Wireless Networking", Prentice Hall Communications Engineering and Emerging Technologies Series, Chapter-5, pp. 186, New Jersey, USA, 2007.

[13] Luise, M., and Reggiannini, R., "Carrier Frequency Recovery in All-Digital Modems for Burst-Mode Transmissions", IEEE Transactions on Communications, COM-43, pp. 1169-1178, February-April, 1995.