

Optimized Phase Noise Compensation Technique using Neural Network

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Abstract

Objectives: The paper designs a technique to optimize the phase noise compensation in the multiple inputs multiple output orthogonal frequency division multiplexing by using the neural network. **Methods/Statistical Analysis:** The phase noise compensation in the orthogonal frequency division multiplexing consists of two parts, one is the inter-carrier interference and other is the common phase error. This paper represents a neural network and Jaya algorithm based technique for the estimation of phase noise. The neural network has been used to remove the common phase error while inter-carrier interference has been removed by the Jaya algorithm. **Findings:** The proposed technique has been compared with three states of art techniques on different block size by using bit error rate. The reduced bit error rate can be identified for each block size. The effectiveness of the technique can be recognized by analyzing the results. **Application/Improvements:** The proposed technique can be used to facilitate the high data rate with better QoS during transmission.

Keywords: Artificial Neural Network, Bit Error Rate, Back Propagation, OFDM, Phase Noise Compensation

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an eminent modulation scheme utilized for the communication over the wired as well as the wireless channels. It is essentially a block modulation scheme in which N symbols are transmitted parallel by using the N sub-carrier^{1,2}. Each sub-carrier has at least recurrence hole to maintain the orthogonality in the time domain while the frequency spectra of the same seems to be overlapped. These sub-carriers are transmitted via frequency-selective channel which is collection of parallel flat frequency sub-channels. The transmitter and the collector utilizes multiple antenna to transmit and receive the signal so known as Multiple Input Multiple Output (MIMO-OFDM) OFDM³

The phase noise is caused due to non-linearity in the local oscillator and can be considered as a parasitic phase modulation of the oscillator's signal. A general signal-level model for a noisy oscillator can be expressed as

$$PHN = e^{j2\pi f t} * e^{j\theta(t)} \quad (1)$$

Where $\theta(t)$ denotes the time-varying PHN and f is the nominal oscillating frequency i.e., carrier frequency for oscillators. The variety in the stage can either be consistent or discrete⁴ discrete stage variety produces discrete signs called spurious frequencies and persistent stage vacillations causes' stage commotion. The PHN of a free running oscillator is expected to take after Brownian movement (Weiner process). PHN causes the PSD (power

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ghastly thickness) to show skirts around the bearer recurrence bringing about a Lorentzian range. It is measured in units of dBc/Hz. The bending acquainted due with the phase commotion (noise) can't be overlooked. The phase commotion remuneration incorporates two sorts of pay, one is because of between Inter-Carrier Interference (ICI) and other is Common Phase Error (CPE). The ICI is considered as white Gaussian clamor happens because of the impedance in the neighbor bearers, while the CPE acquaint the basic stage error with every one of the carriers⁵⁻⁷. The suspicions made to handle the CPE may prompt the diminishment of proficiency in the system. At the point when the proportion of the phase noise capacity and between inter-carrier is little, CPE commands and when the proportion is nearer to unity, ICI rules⁸⁻¹¹.

Various authors has worked on phase noise compensation, resulting a numerous techniques are available for PHN compensation. The author of^{f12} gives the analytical evaluation for the OFDM¹². The author of^{f13} gives a technique for phase noise compensation by removing the IQ imbalance. The technique is fast convergence and produces small residual even for large IQ¹³. The technique designed in 14 uses the correlation properties and phase locked loop for local oscillator to remove the phase noise distortion¹⁴. In¹⁵ the author analyzes the phase noise in doubly selective Rayleigh fading channels¹⁵. The author of^{f16} uses the maximum likelihood to remove the IQ imbalance and phase noise compensation¹⁶ while author of^{f17} analyze the performance of OFDM in the presence of phase noise¹⁷. The authors' motivate the use of swarm intelligence in the OFDM by using the particle swarm optimization for the channel estimation¹⁸. The existing techniques can be improved by using the swarm intelligence technique for phase noise compensation. The paper proposes a technique to compensate the phase noise by using the artificial neural network along with the Jaya algorithm.

2. Phase Noise Modeling

The data sent from the transmitter end over the channel consisting of N subcarriers is receipted at the receiver end can be given as:

$$D_m(n) = \frac{1}{N} \sum_{t=0}^{N-1} D_m(t) e^{j2\pi nt/N} \tag{1}$$

Here, $D_m(n)$ is the nth sub-carrier symbol in the mth interval. To avoid the inter symbol inference, cyclic prefix has been added to the OFDM data each of size say C_g . The phase noise modeling is done at the transmitter as well as the receiver end but the phase noise at the receiver end dominates the phase noise effect¹⁵. The OFDM symbol after considering cyclic and phase noise effect can be given as:

$$Y_m = \text{diag}(e^{j\varphi_m})(D_m * h_m) + \text{noise}_m \tag{2}$$

Here, * represents the convolution operation over the data symbols D_m with the channel impulse response h_m . The noise_m shows the Additive White Gaussian Noise (AWGN) and the φ_m is the phase noise vector can be given as^{19,20}

$$\varphi_m = [\varphi_m(0), \varphi_m(1), \dots, \varphi_m(N-1)]^T \tag{3}$$

This signal in the frequency domain can be given by equation (4).

$$RS_m = K_m * (X_m \cdot H_m) + Y_m \tag{4}$$

Where, X_m and H_m is the transmitted signal and channel transfer function respectively. Y_m is the FFT of AWGN and K_m is the FFT of $e^{j\varphi_m}$. Overall the received signal is summation of two terms i.e. CPE and ICI

$$RS_m(t) = X_m(t)H_m(t)K_m(0) + Y_m(t) + \sum_{l=0, l \neq k}^{N-1} X_m(l)H_m(l)K_m(k-l) \tag{5}$$

The equation (5) can be edited for multiple receiver (say R_n) and transmitter (say T_n) given by (6)

$$Y_m(l) = (e^{j\varphi_{rxm}(l)}) \sum_{m=1}^{T_n} (h_{mn}(l) * x_n(l) e^{j\varphi_{nrxn}(l)}) + \text{noise}_m(l) \tag{6}$$

Which clearly shows that increase in number of transmitter and receiver also increases the phase noise^{21,22}. This paper calculates the phase noise compensation using Jaya algorithm described in next section.

3. Jaya Algorithm

Swarm Intelligence based algorithms are probabilistic algorithms and need controlling parameters for

performance optimization like population size, number of generation etc. Some algorithm specific controlling parameters are also needed like crossover and mutation probability in genetic algorithm²³, inertia weight in the particle swarm optimization²⁴. The improper tuning of such parameters leads to performance degradation of the algorithm. The performance of various swarm intelligence based algorithms like particle swarm optimization, ant colony optimization, artificial bee colony, genetic algorithm, differential evolution etc. is controlled by these controlled by these controlling parameters. Recent development results in few parameters-less algorithms like Teacher Learning Based Algorithm (TLBO)²⁵, Jaya algorithm²⁶ which needs only common parameters (no algorithm specific parameter needed). Jaya algorithm is simple as compared to the TLBO as it needs only one phase to complete its processing²⁶. This work will use the Jaya algorithm described below.

Suppose $O(p)$ is an objective function to be optimized (minimized or maximized). At any particular moment (say a^{th} iteration), s is the population size with each population consisting of m members. The population member obtaining the best value of $O(p)$ say $O(p)_{\text{best}}$ is the best member while the member having lowest value is the worst member say $O(p)_{\text{worst}}$. Then,

$$p_{b,c,a}^m = p_{b,c,a} + r_{1,b,a}(p_{b,best,a} - |p_{b,c,a}|) - r_{2,b,a}(p_{b,worst,a} - |p_{b,c,a}|) \quad (1)$$

Where $p_{b,c,a}$ and $p_{b,c,a}^m$ are the original and modified value of b^{th} member of c^{th} population at a^{th} iteration respectively. $r_{1,b,a}$ and $r_{2,b,a}$ are variables having random value between 0 and 1. $p_{b,best,a}$ and $p_{b,worst,a}$ are best and worst b^{th} member at a^{th} iteration. The $r_{1,b,a}(p_{b,best,a} - |p_{b,c,a}|)$ coefficient of equation (1) moves the value of $p_{b,c,a}$ towards best member while the coefficient $-r_{2,b,a}(p_{b,worst,a} - |p_{b,c,a}|)$ moves the value of $p_{b,c,a}$ away from the worst value. The value of $p_{b,c,a}^m$ is accepted only if $[O(p)_{b,c,a}^m] > O(p_{b,c,a})$ for maximization problem and $[O(p)_{b,c,a}^m] < O(p_{b,c,a})$ for minimization problem. This process is applied to whole population to generate better solution until stopping criteria achieved²². The procedure of Jaya algorithm is given as:

- Initiate population size(s), each population member(m), stopping criteria

- Identify the best and worst population member say best and worst.
- Modify current solution
- $p_{b,c,a}^m = p_{b,c,a} + r_{1,b,a}(p_{b,best,a} - |p_{b,c,a}|) - r_{2,b,a}(p_{b,worst,a} - |p_{b,c,a}|)$
- if $[O(p)_{b,c,a}^m] < O(p_{b,c,a})$ for minimization problem and $[O(p)_{b,c,a}^m] > O(p_{b,c,a})$ for maximization problem then

$$p_{b,c,a} = p_{b,c,a}^m$$

- endif
 - if stopping criteria achieved then
Optimized solution found
 - else
Go to step 2.
 - endif
- The above described procedure can be used to optimize any objective function.

4. Proposed Technique

The proposed methodology to estimate and compensate the phase noise completes in two phases: One phase is the channel estimation phase while the other phase is the data transmission phase. The proposed methodology uses the neural network to estimate the phase noise. The first phase is used to train the neural network over particular characteristics. Then the second phase use trained neural network to estimate the phase noise. In the first phase the block type pilot signals are transmitted to estimate the phase noise along with the channel coefficients. In this phase error back propagation is used to train the neural network to get the exact weight matrix. The input of the neural network is the pilot signal and the output is the phase noise along with the channel coefficients. The unsupervised learning is used in testing phase as no target signal is present to train the network. The second phase transmits the data symbols then used this neural network to get the phase noise. This removes the CPE from the received signal. The ICI cancellation is done by using the JAYA algorithm. The fitness function used for the Jaya algorithm can be given as:

$$F = \alpha * ICI$$

Where $\alpha \in [0 \ 1]$. In this work the value of α is taken as 0.9 to remove the ICI effectively. The Jaya algorithm optimizes each carrier towards the best carrier and far from worst carrier resulting low interference. The complete description is as follow:

Phase 1:

- Transmit the pilot symbol say x .
- Then $y=x'+ P.Ch.x$ where x is the transmitted symbol, P is the phase noise and the Ch is the channel coefficients. Here the P as well as the Ch is not known.
- The neural network gets the input y and the X to estimate the P and Ch .
- In the training phase the exact Ch is known and error back propagation is used to train the network.
- The train network evaluates exact the weigh matrix

Phase 2:

- In this phase data symbols are transmitted.
- These data symbol act as input to neural network.
- The neural network by using the input data symbol gives the phase noise as the output.
- This is the estimated phase noise.
- This estimated phase noise is removed to get the resultant data. This data is free from CPE.
- The ICI is removed from the data by using Jaya Algorithm.
- The fitness function used is $F = \alpha * ICI$ where $\alpha = 0.9$.
- Each carrier is modified by using $C_{b,c,a}^m = C_{b,c,a} + r_{1,b,a}(C_{b,best,a} - |C_{b,c,a}|) - r_{2,b,a}(C_{b,worst,a} - |C_{b,c,a}|)$
- Where each term is already defined in section 3.
- If $[F(C_{b,c,a}^m) < F(C_{b,c,a})]$ only then the carrier is modified.
- The process is repeated for each carrier for maximum number of iterations.

This process removes the phase noise without degrading the performance. This process can also be described by using in Figure 1

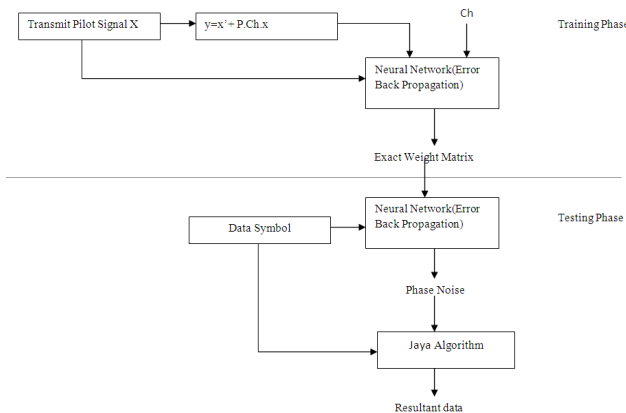


Figure 1. Block diagram.

The implementation and result of the technique are discussed in next section.

5. Result and Discussions

The Bit Error Rate (BER) with respect to the Signal to Noise Ratio (SNR) has been analyzed over QPSK modulation scheme with $N=4, 8, 16, 32$ bit block size on 512 data points. The proposed technique has been compared with three state of art techniques ICM, LMMSE, MCR already described in the first section. Figures 2-5 show the behavior of BER with $N=4,8,16,32$ respectively.

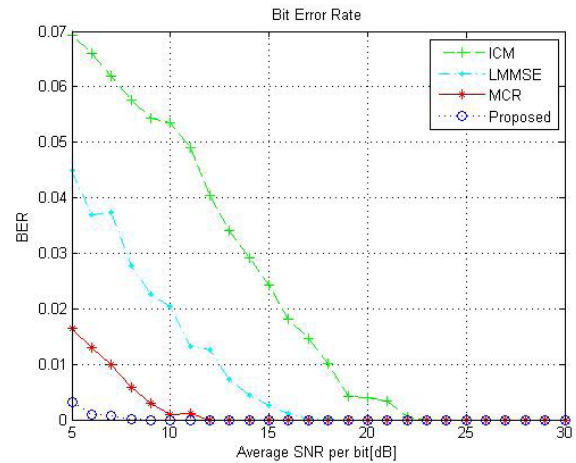


Figure 2. Comparison of BER and average SNR with $N=4$.

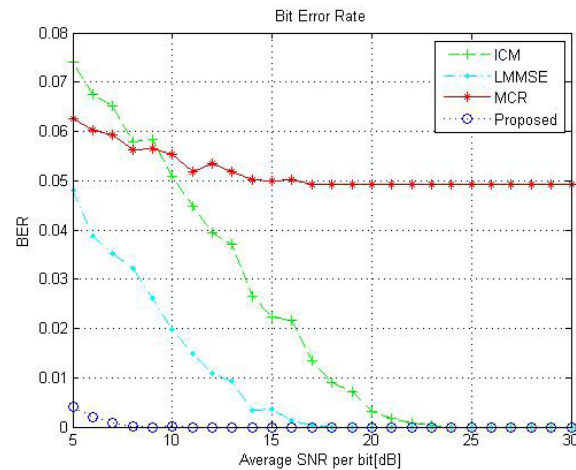


Figure 3. Comparison of BER and average SNR with $N=8$.

The bit error rate has been decreased drastically in the proposed techniques are shown in Figure 2 and 3, as compared to the other technique is due to use of Jaya algorithm for the optimization process along with the neural network. The BER is reducing with the increase in the SNR and it becomes negligible at higher SNR.

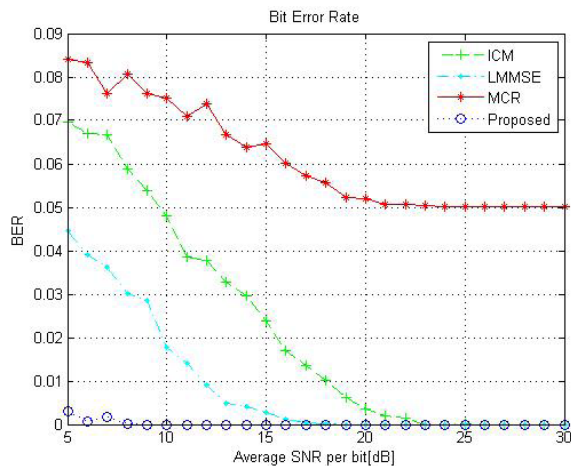


Figure 4. Comparison of BER and average SNR with $N=16$.

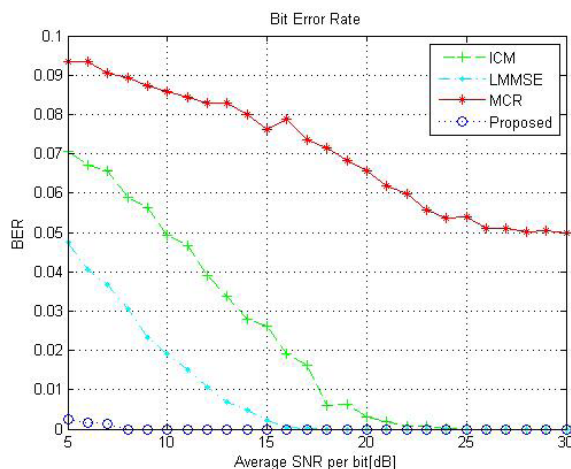


Figure 5. Comparison of BER and average SNR with $N=32$.

Moreover, the BER has been increased in the existing techniques with the increased value of N but the proposed techniques are shown in Figure 4 and 5 doesn't get affected with the value of N . It means the proposed technique is suitable to transmit data with small as well as large block size with less BER.

6. Conclusion

The paper describes an optimization and neural network based phase noise estimation technique. The technique uses the neural network to get the CPE effect and the Jaya algorithm to remove the ICI. The analysis of the BER for the technique with different block size with three states of art algorithms signifies the effectiveness of the technique. In future the work can be extended for channel estimation along with the phase noise compensation.

7. References

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