Adaptive Channel Equalization Using Seagull Optimization with Various Initialization Strategies

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Abstract**—**In a digital communication channel, the transmitted signal may be dispersive causing the information to not be transmitted as same. Due to the distortion, the communication channel is affected known as Inter-Symbol Interference (ISI). To reducing the ISI effect, adaptive channel equalization plays an important role in digital communication. In the proposed method, the Finite Impulse Response (FIR) channel ISI effect is reduced by the proposed optimization algorithm. The FIR channel weight or coefficients are optimized by the proposed Seagull Optimization Algorithm (SOA) with different initialization strategies. Normally, SOA has random initialization of population but to improve the process of adaptive channel equalization, Random Number Generation (RNG), Opposition based learning (OBL) and Quasi-Opposition based learning (QBL) methods are utilized for initialization. The objective function of the equalization process is minimization error values where the error value is estimated based on the desired signal and channel output signal. The experiment is carried out on the MATLAB platform. The proposed method's effectiveness is shown to compare the various initialization methods of RNG, OBL and QBL with SOA. Based on different SNRs, the error value is computed and shows the convergence results.

Index Terms—Adaptive channel equalization, inter-symbol interference, seagull optimization algorithm, etc.

I. Introduction

In digital communication, an adaptive equalization strategy is used to enhance the data transferring over the unknown channels to reduce the effect of ISI. For high speed communication, adaptive equalization is mainly used when systems are not utilized in the differential modulation or frequency division multiplexing schemes [1]. In any communication system, the equalizer is an expensive and important part of the demodulator because it typically uses more than 80% of the total computation required to reduce any signal. Recently, various algorithms are used for adaptive channel equalization namely, Least Mean Square (LMS) [2], Recursive least squares, gradient descent algorithms, Particle Swarm Optimization (PSO) [3] and other swarm based optimization algorithms. Mostly, the LMS algorithm is used for channel equalization because it has a low-computational cost. On the other hand, PSO algorithm is applied in engineering problems. This heuristic method is to find the optimal value for any cost function that falls under the group of swarm intelligence and many of the algorithms are available in animal's social behavior.

Population based optimization mechanisms depend on initial populations with viable solutions. Conventionally, basic RNG has been generally utilized to initiate the population of algorithms. Researchers have not paid great thoughtfulness towards the probable inspiration of population initiation on the effectiveness of algorithms for many years. In current times, the generation of population initiation has been a growing technique. Some of the known methods are random [4], more uniform [5], or somewhat more informative than RNGs [4]. Many published studies can enhance the optimal solution finding probability, reduces the results variance, computational cost and enhance the quality of solutions in algorithms. For channel equalization, Differential Evolution (DE) [6] algorithm is established in channel equalization. The adaptive channel equalization comprises the training of the parameters that receive the transferred data. The equalization process is an optimization problem to minimize the error values where the error value is estimated based on the desired signal and channel output signal.

For channel equalization, communication channels of the FIR channel and Infinite Impulse Response (IIR) are utilized. FIR channels are affected by non-linearity and noise which creates the error as MSE. FIR and IIR channel weights are optimized by the optimization algorithm of Moth Flame Optimization (MFO) in [7]. The better performances have been shown based on frequency response analysis, MSE and BER. Conventional LMS algorithm with PSO has been presented in adaptive equalization [8]. During the optimization process, PSO is used to discover the optimal solutions and LMS algorithm is utilized to avoid the local convergence. A kernel mixed error criterion (KMEC) algorithm is proposed in [9]. The algorithm of KMEC is the combination of two different error methods which are generalized maximum correntropy criterion and logarithmic squared error. The schemes are constructed based on the weighted cost function to develop the KMEC algorithm. From the kernel adaptive filter, the

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KMEC algorithm was derived and the identification of nonlinear channels provides better performance in mixed noise environments. The performance parameters are in terms of convergence, steady-state and MSE. In these types of optimization algorithms, search space dimension is increased and reduces the convergence rate [12]-[15]. Therefore, the different initialization strategies are introduced to optimally select the weight value and to solve the optimization issues.

The contribution of the work as follows: in the communication channel, the noise and ISI effect are reduced by the proposed adaptive equalizer. The proposed adaptive equalizer is constructed based on the FIR channel. The weights of the FIR channel are optimized by the optimization algorithm of the Seagull optimization algorithm with different initialization strategies. RNG, OBL and QBL initialization methods are used in the SOA optimization. The efficiency of the proposed method is shown by the comparative analysis of these different initialization methods in terms of error. The rest of the paper is organized as in Section II explains the process of proposed adaptive channel equalizer. Section III discusses the results of the experimental and finally, the work is concluded in Section IV.

II. Proposed Methodology

In any of the communication channels, the information is transmitted from one end to another one end through earthbound, sky-bound and etc. Once the information is passed through the channel to the receiver from a transmitter that channel gets affected by ISI and noise interference. It will change the information characteristics and degraded information we will get on the receiving side. The information is transferred in the form of a pulse in digital communication which creates the ISI effect and bandwidth problem. Hence, to reduce the ISI problems the equalizers are needed. The equalizers contain coefficients that are optimized by the proposed SOA approach with different initialization strategies. The wireless communication system is modeled as discrete-time with a channel equalizer at the front end of receiver. The transmitted symbols are considered as equi-probable and independent for all $s(n)$ and it will take the (+1, -1) form random binary symbols. In the proposed adaptive equalization method, the wireless channel consists of transmission medium together with filter. Normally, the FIR channel is utilized to model the channel equalization approach. The FIR channel output Equation is expressed in Equation (1) [7],

$$f(n) = \sum_{k=0}^{C-1} h(k)s(n-k) \quad (1)$$

where, number of coefficients and tap coefficients are represented as C and $h(k)$, respectively. Fig. 1 illustrates the proposed block diagram of Adaptive channel equalization.

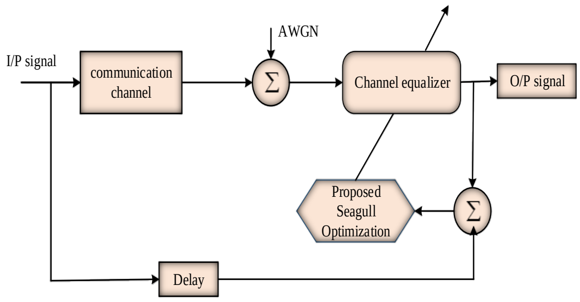


Fig. 1. Block diagram of proposed adaptive channel equalization.

Proposed Seagull Optimization Algorithm

Seagulls are sea birds that live in colonies. Seagulls have migrating and attacking behaviors that are utilized to attacking the prey. To discover a rich and abundant food source, the seagulls move from one location to another location known as seasonal movement as migration [10]. The seasonal movement will provide sufficient energy. The seagull behavior is characterized as below:

The seagulls are travel in their groups during migration. The conflicts among the seagulls can be avoided by the formulation of the different initial locations of seagulls. Thus, the seagulls are moves in a group towards the best seagull with the best survival

1. For the period of migration, seagulls are travel in one group. To avoid conflicts among the other seagulls, it has uses different initial positions.

2. Seagulls can moves towards the best seagull with the best survival in a group.

3. According to the best seagull, initial locations of other seagulls can update their locations.

Birds are migrating over the sea from one location to other location, at this time seagull is attacking the migratory birds. It will create the spiral natural shaped movement for the attacking period.

Migration (Exploration)

In the migration, set of seagulls travels from one location to a new location. This strategy is satisfied by the below three conditions.

Conflicts avoiding: To avoid conflicts among the other seagulls, the variable H is employed for new search agent position calculation.

$$\overrightarrow{S_P} = H \times \overrightarrow{P_S}(t) \quad (2)$$

where, location of search agent is $\overrightarrow{S_P}$, search agent current location is $\overrightarrow{P_S}$, current iteration is denoted as t. In a given search space, the search agent movement behavior is represented as H which is expressed as in Equation (3)

$$H = f_c - (t \times (f_c / i_{max})) \quad (3)$$

Here, control frequency is denoted as f_c which is linearly decreased from f_c to 0 ($f_c = 2$) [10].

Moves to the best search agent: Search agents are move nearer to the best neighbor after the avoidance of conflicts among the search agents.

$$\overrightarrow{M_S} = L \times (\overrightarrow{P_{bS}}(t) - \overrightarrow{P_S}(t)) \quad (4)$$

where, $\overrightarrow{M_S}$ denotes the location of search agent, best search agent is denoted as $\overrightarrow{P_{bS}}$. Balancing between the exploration and exploitation is denoted as L . It is computed by Equation (5)

$$L = 2 \times H^2 \times k \quad (5)$$

where, random number is denoted as k which is lies in 0 to 1 range.

Remaining search agents: Finally, search agent location is updated regarding the best search agent

$$\overrightarrow{D_S} = |\overrightarrow{S_P} + \vec{M}_S| \quad (6)$$

The distance among the search agent and prey is denoted as $\vec{D}_S$.

Attacking

The attacking strategy is the exploitation phase, which exploits the search process experience and the respective information. Seagulls are constantly changed the angle of attack and the speed in displacement. Additionally, it will sustain their height by means of weight and wings. When attack the prey, the movement of spiral is occur in the air. This actions is formulated in the planes of $X, Y\ and\ Z$ is described in Equations (7) to (9) [10].

$$\acute{X} = r \times \cos(c) \quad (7)$$

$$\acute{Y} = r \times \sin(c) \quad (8)$$

$$r = \mu e^{cv} \quad (9)$$

where, spiral radius is denoted as r and random number is denoted as c in $(0 \le c \le 2\pi)$. The spiral shape is defined by the constants of μ and v. Thus, the search agent position is updated by Equation (10).

$$\overrightarrow{P_S}(t) = \left(\vec{D}_s \times \acute{X} \times \acute{Y} \times \acute{Z}\right) + \overrightarrow{P_{bS}}(t) \quad (10)$$

Here, $\overrightarrow{P_s}(t)$ stores the best solution and updates the other search agent's location. During the iteration, search agents update their locations regarding to the best search agent. The variable L is response for the smooth transition among the exploitation and exploration. For adaptive channel equalization, we have used various initialization strategies. The initialization strategies enhance the solution accuracy and convergence speed. Here random number generation, Opposition Based Learning, and Quasi-opposition Based Learning. The seagull optimization outcomes are getting based on various initialization procedures.

Random number generation

For many years, the RNG is the common optimization method. Seagull optimization is utilizing the RNG initialization. Within the search space, it will generate uniform random numbers. However, RNGs cannot create a suitable uniform distribution of points. This defect worsens while the dimension of the search space increases or the numbers of points is decreasing [4]. Hence in optimization issues, RNGs drop their efficacy since the search space dimension is too large and the size of population is not great sufficient to model all areas. In general, the functions of different algorithms and RNG systems can affect the generated point's quality.

Opposition Based Learning (OBL)

OBL initialization is the significant approach in optimization algorithms. Let$X_i(x_{i,1}, x_{i,2}, \ldots, x_{i,D})$ be the i^{th} individual of the population and (a_i, b_j) is used to bind the each variable$x_{i,j}$. Therefore, the opposite point is defined as in Equation (11) [5],

$$\tilde{x}_{i,j} = a_j + b_j - x_{i,j}, \qquad j = 1,2, \ldots, D \quad (11)$$

In the OBL technique, random population is generated first to create the promising population known as original population. After, the original population opposition points are computed based on Equation (11). At this time, both populations are combined and the best individuals are designated to formulate the initial population for the SOA according to the fitness process.

Quasi-opposition Based Learning (QOBL)

In the process of adaptive channel equalization, the FIR channel coefficients are initialized in the first step. A number of samples (k) are produced and delivered via the channel. A certain amount of SNR in AWGN is added with channel which is passed via the non-linear channel. The SOA parameters corresponding to equalizer coefficients are initialized as different strategies as RNG/ OBL/ QBL. The nonlinear channel output subject to noise and distortion is passed as input to the equalizer. As a result, the equalizer output is estimated based on the error between the estimated signal and desired signal. Therefore, a k number of error signals are generated and the mean of the squared error gives the MSE and this process is repeated for a number of times. Based on the SOA, the optimal coefficients are selected. Until MSE decreases the optimization process is repeated. Once we attain the lowest MSE value all the parameters will become identical and terminate the process. Finally, the proposed adaptive equalizer attains the optimal coefficients. [Fig.2] shows the flow chart of the proposed adaptive equalization process

QBL is not a combined version of OBL and QRS. In fact, the OBL modified version is QBL that seeks to raise population uniformity. According to Equation (11), the quasi-opposition point of X_i, $\breve{X}_i(\breve{x}_{i,1}, \tilde{x}_{i,2}, \ldots, \breve{x}_D)$ is [11],

$$\breve{x}_{i,j} = \begin{cases} rand(k_j, \breve{x}_{i,j}), & if\ x_{i,j} \le k_j \\ rand(\breve{x}_{i,j}, k_j) & if\ x_{i,j} > k_j \end{cases} \quad (12)$$

where $k_j = \frac{b_j - a_j}{2}$, and random number is denoted as $rand\ (\alpha, \beta)$ which drawn uniformly in the range of (α, β). Like the OBL, when the computation of quasi-opposition points, quasi and original populations are integrated into a larger population. At that time, the best resolutions are chosen based on the channel equalization fitness function. According to these three strategies, the channel equalization is performed with seagull optimization algorithm.

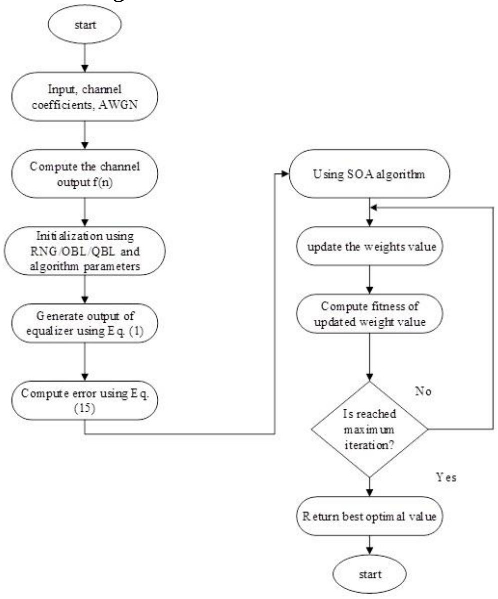


Fig. 2. Flow chart of proposed method.

In the process of adaptive channel equalization, the FIR channel coefficients are initialized in the first step. A number of samples (k) are produced and delivered via the channel. A certain amount of SNR in AWGN is added with channel which is passed via the non-linear channel. The SOA parameters corresponding to equalizer coefficients are initialized as different strategies as RNG/ OBL/ QBL. The nonlinear channel output subject to noise and distortion is passed as input to the equalizer. As a result, the equalizer output is estimated based on the error between the estimated signal and desired signal. Therefore, a k number of error signals are generated and the mean of the squared error gives the MSE and this process is repeated for a number of times. Based on the SOA, the optimal coefficients are selected. Until MSE decreases the optimization process is repeated. Once we attain the lowest MSE value all the parameters will become identical and terminate the process. Finally, the proposed adaptive equalizer attains the optimal coefficients. Fig. 2 shows the flow chart of the proposed adaptive equalization process.

III. Simulation Resutls

The proposed technique experiments are carried out on MATLAB 2018b version with 4GB RAM. The proposed equalizer performance is evaluated based on the SOA with various initialization strategies like RNG [4], OBL [5] and QBL [11]. For the adaptive channel equalization, the simulation is conducted on the various initialization methods. SOA based channel equalization experiment is simulated with two channels which are described in Equations (13) and (14).

$$C_1 = 0.2600 + 0.9300z^{-1} + 0.2600z^{-1} \quad (13)$$

$$C_2 = 0.3482 + 0.8769z^{-1} + 0.3482z^{-2} \quad (14)$$

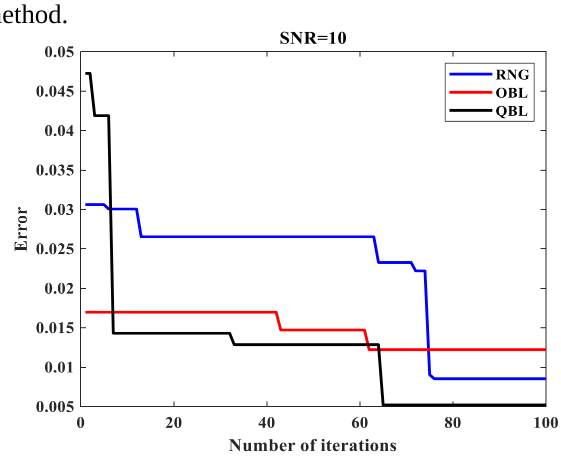
The 30 dB AWGN noise is added to the channel output which gives as the input to the proposed adaptive channel equalizer. The objective function of MSE is computed based on the Equation (15),

$$Error = estimated\ signal - desired\ signal \quad (15)$$

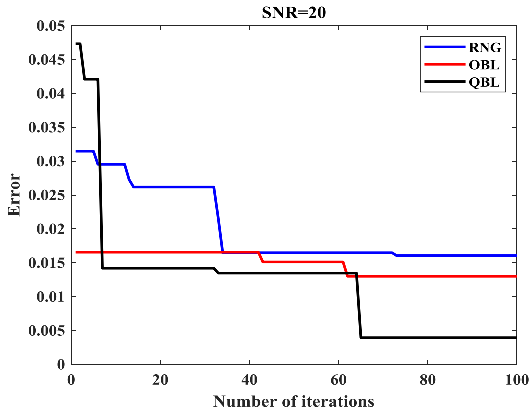
Under various SNR conditions, the equalizer is to be tested based on the characteristics of error. During training, the computational time of the equalizer gives convenience for online applications. The algorithm speed is decided by the lower run time.

The adaptive channel equalization performance is validated SOA with RNG, OBL and QBL. Fig. 3 illustrates the error convergence of different SNR as 10 dB, 20 dB, 30 dB and 40 dB. For 10 dB in Fig. 3(a), the SOA with QBL initialization method is quickly converging and QBL gives the minimum error value (0.005) compared to RNG (0.085) and OBL (0.013) in Fig. 3(b). In 20 dB SNR, QBL (0.045) method achieves minimized error compared to OBL and RNG. To compare with OBL and RNG, OBL (0.014) is quickly converges than the RNG (0.017).

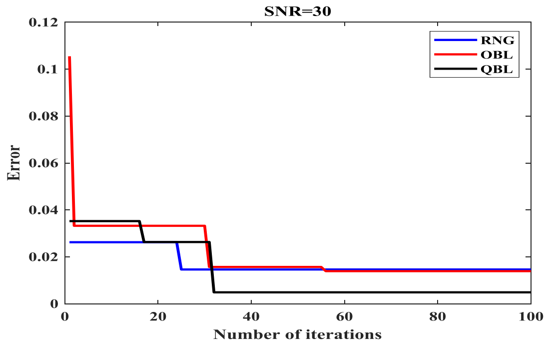
For 30 dB comparison, SOA with QBL method (0.008) has achieved minimum error compared to OBL (0.017) and RNG (0.018), which is displayed in Fig. 3(c). For 40 dB comparison, SOA with QBL method (0.009) has achieved minimum error compared to OBL (0.014) and RNG (0.02), which is displayed in Fig. 3(d). Here, the SOA with OBL is non-converging with a constant error of 0.014. From the overall error convergence comparison of proposed method, the SOA with QBL based strategy has achieved better performance than the other. Hence, the adaptive channel equalization is successfully optimizing the channel coefficients in the SOA with QBL method.



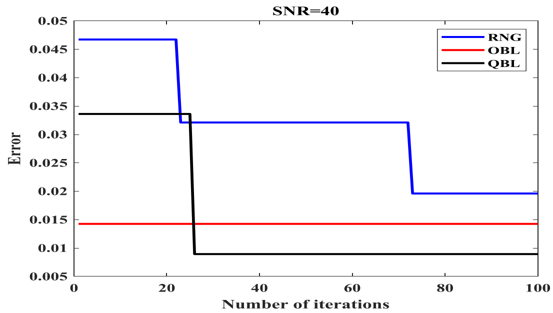
(a)



(b)



(c)



(d)

Fig. 3. Error convergence for a) SNR 10dB, b) SNR 20dB, c) SNR 30dB and d) SNR 40dB.

IV. Conclusion

In this paper, SOA with different initialization based adaptive channel equalizer was proposed to reduce the effect of ISI. The FIR channel contains weight values that are optimized by the proposed algorithm. Based on the MSE, the channel weights are optimized to reduce the ISI effect and noise from the output of the communication channel. The different initialization strategies of RNG, OBL and QBL are utilized in the SOA initialization. Increasing different population strategies gives a better result in the optimization approaches. The proposed method performance is displayed with different initialization methods to show the effectiveness. For the different SNR error converges, the proposed SOA with QBL method gives better performance. In the future, hybrid optimization algorithms and machine learning algorithms will be utilized in the adaptive channel equalization process.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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