World Applied Sciences Journal 18 (6): 836-844, 2012
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2012.18.06.906

Adaptive Resource Allocation in OFDM Systems Using GA and Fuzzy Rule Base System

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Abstract: Adaptive resource allocation is one of the hottest topic in almost every field of study and research now a day. It promises optimal utilization of resources while satisfying certain number of constraints. A similar constrained optimization problem has been solved for OFDM environment where channel hostilities are mitigated and throughput is maximized by adaptively selecting code rate, modulation symbol and transmits power. Many adaptive bit and power loading techniques have been investigated in the literature for enhancement of transmission rate in combination with Orthogonal Frequency Division Multiplexing (OFDM). In these systems mainly adaptive coding modulation or adaptive power was the focus but not both. In this paper, two new schemes are proposed to adapt code rate, modulation size as well as transmit power based upon channel conditions and quality of service demand by any subcarrier. Adaptive coding and modulation is done by using a Fuzzy Rule Base System (FRBS) to enhance the achievable data rate in an OFDM system with a fixed target bit error rate and fixed transmit power for each subcarrier. Moreover, for power adaptation two approaches are proposed, first the conventional water-filling algorithm and in second technique Genetic Algorithm is used to choose the optimum power vector. Both of these schemes are tuned in conjunction with FRBS. Moreover, the value of constant K for water-filling algorithm is calculated analytically. Simulation results show that water-filling performs algorithm better than flat power distribution while Genetic Algorithm assisted adaptive power outperforms both fixed and water-filling assisted adaptive power.

Key words: Water-filling principle · OFDM · FRBS · BER · Adaptive Modulation and Coding · Modulation Code Pair

INTRODUCTION

Use of evolutionary, soft-computing and hybrid intelligent algorithm for solution of optimization problems in various fields of engineering is an emerging area of research now a day. These algorithms are attractive due to their nonlinear nature and easy hardware/software implementation.

Adaptive Orthogonal Frequency Division Multiplexing (AOFDM) is one of the successful candidates for many 3rd Generation (3G) and 4th Generation (4G) Systems. In this technique a single very high data rate stream is divided into several low data rate streams using Inverse Fast Fourier Transform (IFFT). Then these streams are modulated over different orthogonal subcarriers.

A Multiuser subcarrier and bit allocation along with adaptive cell selection for transmission was proposed by Zhang [1] where 1.6dB gain was achieved compared to fixed subcarrier allocation.

A low complexity algorithm for proportional resource allocation in Orthogonal Frequency Division Multiple Access (OFDMA) system was proposed in 2004, where linear method and root finding algorithm were used to allocate power and data rates to users [2]. In [3] a gradient based solution was proposed for single user downlink scheduling and resource allocation for downlink OFDM wireless systems and a 96.6% utility was achieved. An Adaptive data transmission in downlink MIMO-OFDM system with pre-equalization was investigated using Water-filling algorithm and adaptive LQ decomposing [4].

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A Genetic Algorithm (GA) based adaptive resource allocation scheme was proposed by Reddy [5], to increase the user data rate where water-filling principle was used as a fitness function. Moreover, it was shown that chromosome length helps to achieve optimum power requirement.

A subchannel allocation based on bidding model and auction algorithm proposed by [6], where throughput was sustained but user data rates were compromised. Moreover, auction algorithm allocates subchannel to user those really require that subchannel.

A novel efficient resource allocation algorithm for multiuser OFDM system using a joint allocation method and root finding algorithm to achieve good performance even with low signal to noise ratio (SNR) was proposed by [7].

Another interesting paper with adaptive resource allocation based on modified genetic algorithm (GA) and particle swarm optimization (PSO) for multiuser OFDM system was proposed by [8]. Genetic algorithm has been modified by using a fractional generation gap. It converges faster than the original one and it was also found that PSO performs better than GA.

An approach akin to the previous one, ant colony optimization (ACO) evolutionary technique for subcarrier allocation in OFDMA-based wireless system was proposed by [9]. Technique was capable of finding one optimal solution in a short period of time.

Adaptive subcarrier and power allocation with fairness for multi-user space-time block-coded (STBC) OFDM system was investigated in contrast to Greedy algorithm as well as water-filling principle [10]. An optimization problem for power constraints and use Genetic algorithm (GA) to maximize the sum capacity of OFDM system with the total power constraint was investigated in [11]. Also it was shown that Genetic algorithm performs better than conventional methods.

A scheme for resource allocation in downlink Multiple Input Multiple Output (MIMO) OFDMA with proportional fairness where dominant Eigen channels obtained from MIMO state matrix are used to formulate the scheme with low complexity in [12], scheme provides much better capacity gain than static allocation method. A PSO based Adaptive multicarrier cooperative communication technique which utilizes the subcarrier in deep fade using a relay node in order to improve the bandwidth efficiency [13] where centralized and distributed versions of PSO were investigated.

A low complexity subcarrier and power allocation technique based upon GA to maximize the sum of user data rates in MIMO-OFDMA system was proposed in [14]. Al-Janabi *et al*. [15] proposed a bit and power allocation strategy for Adaptive Modulation Coding (AMC) based MIMO-OFDMA WiMAX system. The scheme maximizes the average system throughput by allocating the available resources optimally among the utilized bands depending on the corresponding channel conditioning and total transmission power constraints. The power allocation algorithm distributes the transmission power among the bands of all transmit antennas according to the power constraints and the channel state information (CSI) and the bit allocation algorithm, selects the suitable modulation coding scheme (MCS) options for different bands based on the assigned power and the channel conditions.

Another GA based efficient real-time subcarrier and bit allocation for multiuser OFDM transmission technique was proposed in which overall transmit power was minimized under user constraint [16]. A subcarrier-chunk based technique in which resource allocation problem for the downlink of OFDMA wireless systems was proposed in [17]. The scheme dramatically reduces the complexity and fairness among users' data rates is very satisfactory despite the loss with respect to the unconstrained case where the only target is the maximization of the sum data rate.

In this paper we proposed a Fuzzy Rule Base System (FRBS) to adapt the code rate and modulation symbol according to the varying channel conditions. The inference engine (IE) of FRBS is built upon set of rules that are derived from simulation results obtained by analyzing various practical channel codes (convolutional codes) in contrast to modulation schemes (QAM family) over an AWGN channel. Once the FRBS was designed we examined the role of flat power, adaptive power with water-filling principle and Genetic Algorithm based adaptive power.

The remainder of this paper is organized as follows. In section 2, system model is introduced. Performance of different codes in conjunction with different modulations is presented in section 3. The results of section 3 are used in section 4 to formulate a constrained optimization problem. In section 5 a brief introduction to Fuzzy Rule Base is given that is used to solve the optimization problem formulated in previous section. Section 6 contains discussion of two loading techniques that is water-filling algorithm and Genetic Algorithm; Section 7 contains the performance comparison of this scheme with various other adaptive resource allocation schemes, while section 8 concludes the paper.

System Model: The system model considered is OFDM equivalent baseband model with N number of subcarriers. It is assumed that complete CSI is known at both transmitter and receiver. The frequency domain representation of system is given by

$$r_k = h_k.\sqrt{p_k}.x_k + z_k;\ k = 1,2,......,N \quad (1)$$

Where r_k, h_k, $\sqrt{p_k}$, x_k and z_k denote received signal, channel coefficient, transmit amplitude, transmit symbol and the Gaussian noise of subcarrier k = 1,2,...,N, respectively.

The overall transmit power of the system is $P_{total} = \sum_{k=1}^{N} p_k$ and the noise distribution is complex Gaussian with zero mean and unit variance.

It is assumed that signal transmitted on the kth subcarrier is propagated over an independent non-dispersive single-path Rayleigh Fading channel and where each subcarrier faces a different amount of fading independent of each other. Hence, the channel coefficient of kth subcarrier can be expressed as:

$$h_k = \alpha_k e^{j\theta k};\ k = 1,2......,N \quad (2)$$

Where α_k is Rayleigh distributed random variable of kth subcarrier and the phase θ_k is uniformly distributed over $[0, 2\pi]$.

Coded Modulation: In this section various standard code rate in contrast to various modulation schemes will be presented in terms of performance graphs. In subsequent section these graphs will be used for obtaining rules for creation of Fuzzy Rule Base System. For experimentation the sequence of operations is carried out in same way as given in Figure 2. Following is the detail of each component.

Encoder: The codes used in this paper are non-recursive convolutional codes with code rates taken from the set C with constraint length 3.

$$C = \{1/4,1/3,1/2,2/3,3/4\} \quad (3)$$

Modulator: In this paper we have utilized the symbols taken from Quadrature Amplitude Modulation (M-QAM), with rectangular constellation. The modulation symbols are taken from the following set.

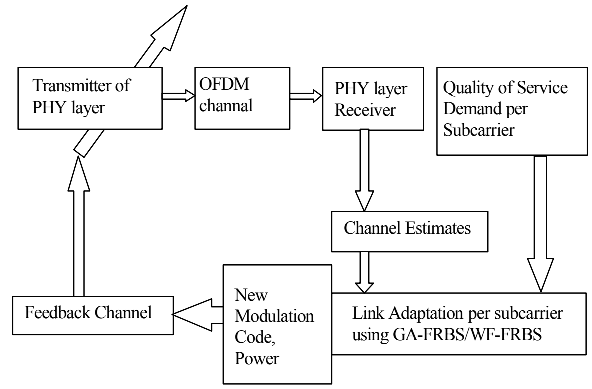

Fig. 1: Brief diagram of proposed System

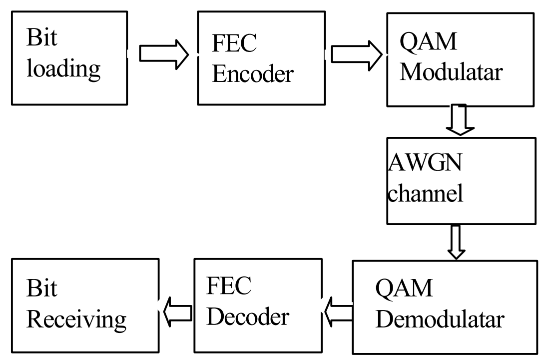

Fig. 2: Brief diagram of simulations

$$C = \{2,4,8,16,32,64,128\} \quad (4)$$

Channel: Additive White Gaussian Noise (AWGN) channel is assumed for simulations. The choice this channel is appropriate in the sense that other channel parameters can be incorporated later.

Demodulator: Standard optimal Maximum Likelihood demodulator is used.

Decoder: For decoding, standard soft output Viterbi decoder is used.

The transmitted signal is first encoded using standard feed-forward convolutional encoder having code rate from the set C given in equation (3) and then the encoded signal is modulated using the elements of QAM from the set M given in equation (4). In this way we have following pairs of coding and modulation schemes by cross product of sets C and M, which yields,

$$P = C \times M = \{(c_i, m_j); \forall c_j \in C, \forall m_j \in M\} \quad (5)$$

Then graph for each pair is obtained over an Additive White Gaussian Noise (AWGN) channel. The selection of this channel is suitable in a sense that it reflects the proper relationship between signal to noise ratio (SNR) and data rate achievable under a specific target bit error rate (BER). Some of these graphs are depicted in the Figures 3, 4 and 5 with rate 1/4, 1/3 and 1/2 respectively. All of the modulation schemes are investigated with each code rate. These graphs will be used to populate the rule base for Fuzzy Rule Base System in fifth section.

Rate Optimization: In order to maximize the rate for overall OFDM system following constrained optimization problem will be considered.

$$\begin{aligned} &\max \quad R_{Total} = \frac{1}{N}\sum_{i=1}^{N} r_i \\ &\text{s.t,} \\ &BER_i \le BER_{QoS_i} \\ &and \\ &P_{Total} = \sum_{i=1}^{N} p_i < P_T \end{aligned} \tag{6}$$

Where $r_i = (\log_2(M))_i\, R_{c,i}$ is the bit rate of ith subcarrier. P_T is the total transmit power and BER_{QoSi} is target BER that depends upon a specific quality of service (QoS) request or application requirement over ith subcarrier, while N is total number of subcarriers in OFDM system.

Adaptive system will make use of these facts and it will use appropriate modulation code pair (MCP) for each subcarrier depending upon channel condition at that subcarrier, that is, over a subcarrier with good channel condition a high code rate with a high QAM can be used and vice versa. Similarly, the blend of different MCP can be used to cope up with entire spectrum of channel variations.

As far as demonstration is concerned, all of the modulation-code pairs are investigated, but obviously not all pairs will be used. Only a subset of these pairs will be considered due to the fact that two or more pairs may provide same throughput (modulation code product) but with different SNR demands. So, among them, the pair with least SNR demand will be chosen.

Fuzzy Rule Base System: A fuzzy rule base system (FRBS) is proposed and designed, which is capable of deciding the best modulation code pair (MCP) for the next

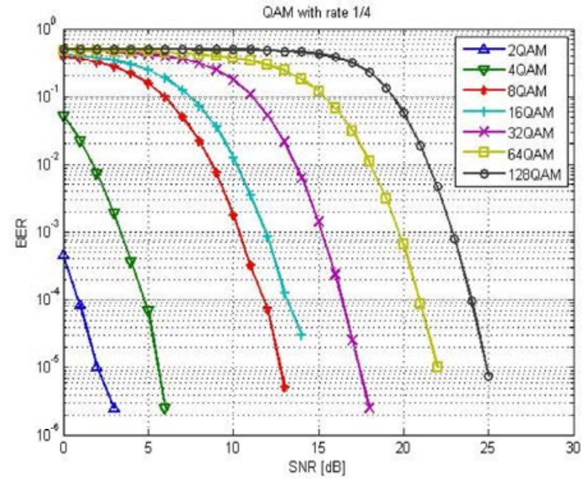

Fig. 3: BER comparison of different QAM modulations using rate 1/4 convolutional codes

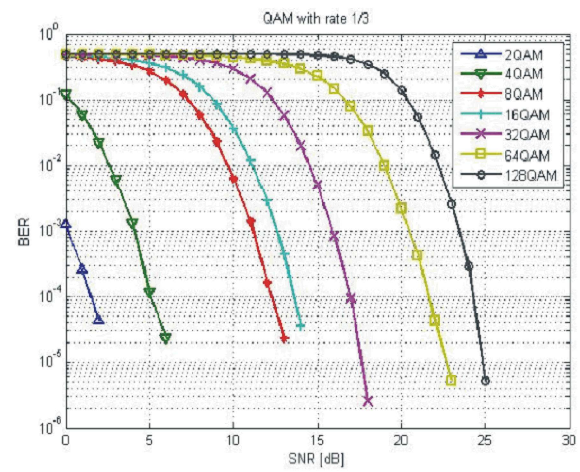

Fig. 4: BER comparison of different QAM modulations using rate 1/3 convolutional code

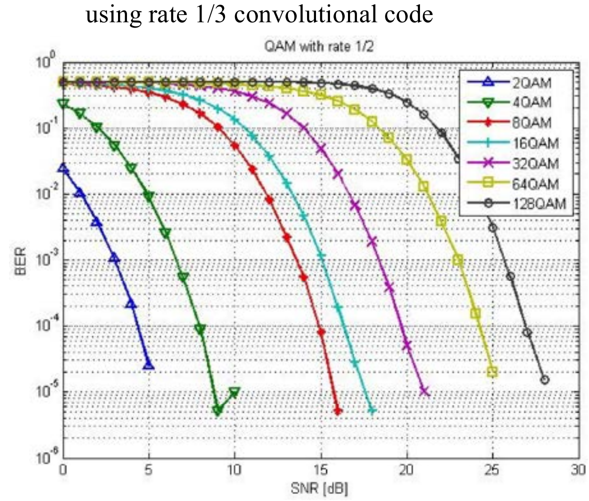

Fig. 5: BER comparison of different QAM modulations using rate 1/2 convolutional code

transmission, based upon the channel statistics. Fuzzy logic is best suited for the situations that are vague, ambiguous, noisy or missing certain information. Also fuzzy systems are very easy to implement in hardware.

This fuzzy rule base system (FRBS) is used to optimize the cost function given in eq (6). It will be decided that which modulation code pair is suitable for a specific subcarrier based upon the individual channel state information (CSI) at the subcarriers and the Quality of Service demand. The steps involved in creation of FRBS are described below.

Graphs: Graphs for different code rates and modulation symbols are obtained (section III).

Data Acquisition: From the results obtained in section-III, those code-modulation pairs that fulfill different BER demands depending upon different quality of services i.e. BER_T = 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2} etc are obtained. This is obtained by drawing straight horizontal lines on the graphs shown in Figures 2-5, on certain BER points (Quality of Service) like 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}. Then the points of intersection of these lines and the curves (representing a code and a modulation) are noted and the appropriate SNR value is noted. So the information obtained can be expressed as “for a given SNR and specific QoS which modulation code pair can be used”.

Rule Formulation: Rules for every pair are obtained by the appropriate fuzzy set used. That is by putting complete pair in input/output set and a rule generated for each pair.

Elimination of Conflicting Rule: The rules having same IF part but different THEN parts are known as conflicting rules. This appears when more than one modulation code pair (MCP) are available for given specification. For instance, there is a rule whose THEN part contains three different MCP namely, [8, 1/2], [16, 2/3] and [16, 3/4]. Now [16, 3/4] is best among the rest since its throughput is 4x3/4=3 while others have 3x1/2=1.5 and 4x2/3=2.67 respectively.

Similarly, sometime there could be two different pairs with same throughput like [2, 1/2] and [4, 1/4] both have same throughput that is 1x1/2=0.5, then [2, 1/2] will be chosen since it exhibits less modulation/demodulation and coding/decoding cost.

Completion of Lookup Table: Since in lookup table scheme we may not have complete number of IO pairs, then those parts are filled by heuristic or expert knowledge. For example, a modulation code pair is suggested by rule for a certain SNR and QoS. Then that rule can also be used for slightly above SNR and poor QoS. For instance, [128,3/4] is suggested for 25dB SNR and BER 10^{-3}, then this pair can be used for 26-30dB SNR and 10^{-2} BER cases as well. Since if a modulation code pair performs for lower SNR, then it can easily sustain in higher SNR situations. Similarly, if a MCP performs for a good QoS then it can sustain for poor QoS demands.

Fuzzy Rule Base Creation: Using the Lookup table in above phase, Fuzzy Rule Base is created using Fuzzy Logic Toolbox in MATLAB. Further details are given in next section. Table look-up scheme for design of this fuzzy rule base system is used.

The input-output pairs for design of FRBS are of the form;

$$(x_1^s, x_2^s; y^s); s = 1,2,3.......S \quad (7)$$

Where x_1^s represents received SNR, x_2^s represents required BER (QoS) and y^s represents the output MCP suggested by FRBS, so the rule format will be given as below;

$$\{\text{IF } (x_1 \text{is L1 and } x_2 \text{ is Q7) THEN y is P2}\} \quad (8)$$

Following is the brief description of different components of fuzzy rule based system used. Design of the FRBS is carried out in MATLAB 7.0 standard Fuzzy System Toolbox.

Fuzzy Sets: Sufficient numbers of fuzzy sets are used to cover the input output spaces. There are two input variables namely *received SNR* and *minus log bit error rate* (MLBER) that represents a QoS. The reason taking MLBER is because BER of a required QoS is given by 10^{-2}, 10^{-3}, 10^{-4} etc while the range of fuzzy variable should be equally spaced and quantifiable. So to get this, following operation is done first.

$$\begin{aligned} MLBER &= -\log(BER) \\ BER &= 10^{-q} \\ MLBER &= -\log(10^{-q}) = q \end{aligned} \quad (8)$$

There is one output variable for modulation code pair MCP.

Fuzzifier: Standard triangular fuzzifier is used with AND as MIN and OR as MAX.

Rule Base: Rule base contains rules against all the IO pairs. As there are thirty-one sets (L_0 to L_{30}) for first input variable named SNR and about sixteen sets (Q_1 to Q_{16}) for input variable MLBER. Hence there are 496 rules in rule base. Rule base is complete in a sense that rules are defined for all possible combinations of input space.

Inference Engine: Standard Mamdani Inference Engine (MIE) is used that will infer which input pair will be mapped on to which output point.

De-Fuzzifier: Standard Center Average Defuzzifier (CAD) is used for defuzzification.

An overview of entire fuzzy rule base system is shown in Fig-6 while a specific view of rule base is given in Fig-7. Fig-8 depicts the rule surface that shows that by increasing SNR the throughput is maximized. Also on the other hand for poor QoS demands throughput is more than that of high QoS demands. A combined effect of both input variables namely SNR and QoS can be seen in that figure. For the highest value of SNR and lowest value of QoS, throughput of the system approaches to 5bits/s/Hz.

Adatptive Power/Loading Techniques: This section contains the detailed discussion about the proposed adaptive power methods proposed in this system. Two methods are investigated for making transmit power adaptive namely, the water-filling algorithm and second is Genetic Algorithm. Though these techniques are not new and in literature many researchers used them but innovative use of these technique is that both of the techniques have been investigated in conjunction with Fuzzy Rule Base System designed in previous section. So this is a combined effort to make code rate, modulation size and power adaptive.

Water-Filling Principle: Water-filling principle has been used for multicarrier loading problems. It is restated here for sake of reference.

"Maximize the bit rate R_{Total} for the entire multichannel transmission system; through an optimal sharing of the total transmit power P_T between the N sub-channels, subject to the constraint that P_T is maintained constant."

In contrast to our system this phenomenon can be written mathematically as,

$$p_i + \frac{\sigma_i^2}{|H(f_i)|^2} = K; 1 \le i \le N \qquad (9)$$

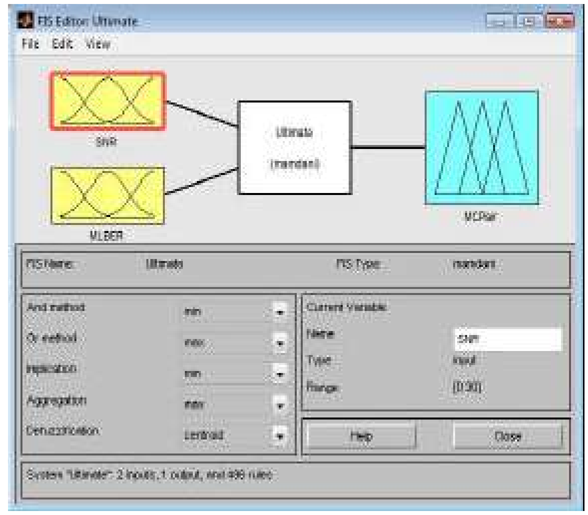

Fig. 6: An overview of Fuzzy Rule Base System

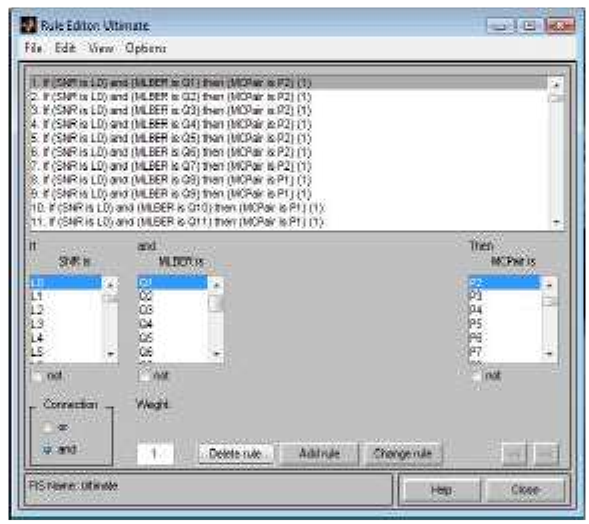

Fig. 7: The Rule Base

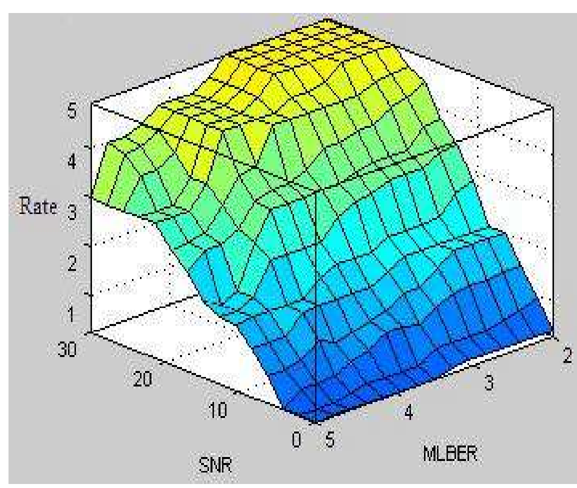

Fig. 8: Rule surface

Where p_i is transmit power, σ_i^2 is noise variance (power) and $|H(f_i)|$ magnitude response at subchannel i respectively.

The choice of constant K depends upon application and it is under designer control. That is, the sum of the transmit power and noise variance (power) scaled by inverse of square of channel (subchannel) magnitude response must be maintained constant for each subchannel.

This can also be written as;

$$p_i + \frac{1}{(CNR)_i} = K; 1 \le i \le N \tag{10}$$

Where

$$(CNR)_i = \frac{|H(f_i)|^2}{\sigma_i^2} \tag{11}$$

Another contribution of the proposed scheme is that the value of the constant K is calculated analytically and given below while derivation can be found in Appendix-I.

$$K = P_{avg} + \frac{1}{N}\sum_{i=1}^{N}\frac{1}{(CNR)_i} \tag{12}$$

Where P_{avg} is the average transmit power per subcarrier and $(CNR)_i$ is given in equation 11. The throughput of this loading algorithm will be calculated by equation 13, while the power vector P will be found by water-filling algorithm using equation 10.

Genetic Algorithm: Genetic Algorithm is a biologically inspired evolutionary algorithm based upon the motive "survival of the fittest". In this scheme it is proposed for finding the optimum power vector that maximizes the overall throughput of the OFDM System while satisfying the total power constraint as well as quality of service (QoS) demand per subcarrier (equation 5).

Figure 13 contains the block diagram of fitness function being applied for sake of finding the fitness of a chromosome (transmit power vector). So the power vector with the highest fitness (throughput) would be chosen for transmission. The fitness function can be written mathematically as;

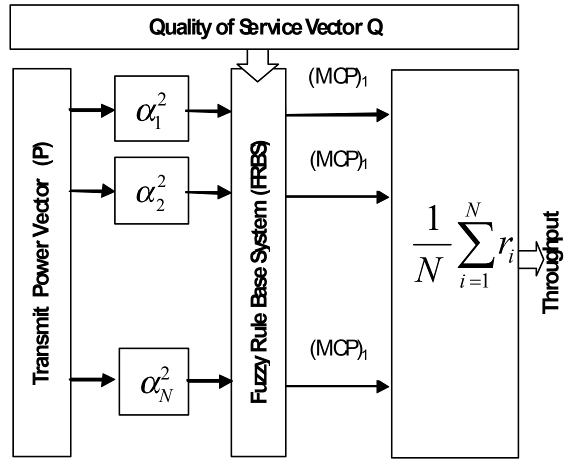

Fig. 9: Fitness Block

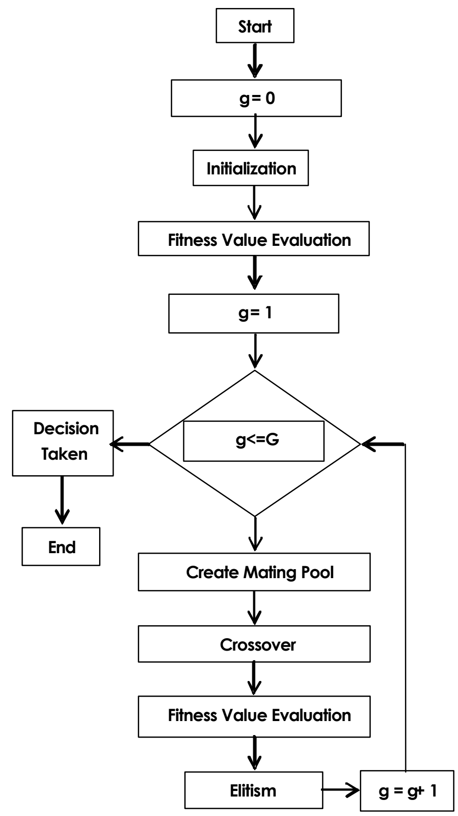

Fig. 10: Flowchart of Genetic Algorithm

$$\begin{aligned} R &= \frac{1}{N}\sum_{i=1}^{N} r_i \\ &= \frac{1}{N}\sum_{i=1}^{N} (\log_2(M))_i R_{C,i} \\ &= \frac{1}{N}\sum_{i=1}^{N} FRBS(p_i, \alpha_i, QoS_i) \end{aligned} \tag{13}$$

The algorithm used is described below while flowchart of the Genetic Algorithm is given in figure 10.

Algorithm:

- Take the power vector of length N (total no. of subcarriers) with flat power distribution
- Obtain the first generation
- Find the fitness of the generation by the equation 13
- Sort the chromosomes with respect to their fitness
- Create the mating pool
- Apply the crossover operation
- Obtain the new generation
- Find fitness of new generation
- Check whether total generations reached
- If yes take decision and terminate
- Otherwise go to step-3

RESULTS

In this section proposed schemes are demonstrated and compared with other schemes. Fig-11 to Fig-14 show the comparison of Genetic Algorithm with Fuzzy Rule Base System (GA-FRBS) assisted Adaptive Coding, Modulation and Power (ACMP) scheme; Water-Filling with Fuzzy Rule Base System (WF-FRBS) assisted ACMP; and simple FRBS assisted Adaptive Coding and Modulation (ACM). In this figure Quality of Service (QoS) demand per subcarrier was assumed to be 10^{-2}, 10^{-3}, 10^{-4} and 10^{-4} respectively.

For these simulations channel attenuation constants are assumed to be $0.1 \le \alpha_i \le 0.4$; i=1,2,...,N while number of subcarriers N=128.

From the above figures it can easily be deduced that GA-FRBS assisted Adaptive coding, modulation and power scheme performs better than WF-FRBS assisted ACMP while WF-FRBS assisted ACMP scheme performs better than that of FRBS assisted ACM with fixed transmit power.

CONCLUSIONS

In this paper adaptive resource allocation schemes are proposed and investigated for OFDM systems. First scheme is, Genetic Algorithm and Fuzzy Rule Based System assisted Adaptive Coding; Modulation and Power scheme. Second scheme is Water-Filling and Fuzzy Rule Base System assisted Adaptive Coding, Modulation and Power scheme. In these techniques adaptive coding and modulation is achieved by designing a Fuzzy Rule Base System while adaptive power is achieved by Genetic Algorithm and Water-filling principle. So by using the above schemes system would be able to adapt code rate, modulation symbol as well as transmit power in order to achieve a certain bit error rate (QoS) and to enhance the overall data rate of the OFDM system.

Simulation results show that GA with FRBS based Adaptive resource allocation performs better than WF with FRBS based adaptive resource allocation. Also the fixed transmit power does not perform that good as adaptive power schemes.

ACKNOWLEDGMENT

This research work is sponsored by Higher Education Commission (HEC), of Pakistan.

APPENDIX-I

The exact value for the constant K in Water-filling algorithm is analytically found by the following derivation.

$$p_i + \frac{1}{(CNR)_i} = K$$

$$\sum_{i=1}^{N} p_i = \sum_{i=1}^{N} \left(K - \frac{1}{(CNR)_i}\right)$$

$$P_T = \sum_{i=1}^{N} K - \sum_{i=1}^{N} \frac{1}{(CNR)_i}$$

$$P_T = NK - \sum_{i=1}^{N} \frac{1}{(CNR)_i}$$

$$K = \frac{P_T}{N} + \frac{1}{N} \sum_{i=1}^{N} \frac{1}{(CNR)_i}$$

$$K = P_{avg} + \frac{1}{N} \sum_{i=1}^{N} \frac{1}{(CNR)_i}$$

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