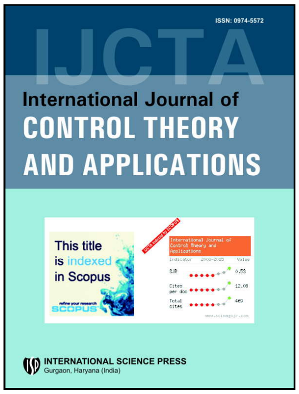

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Application of Soft computing in Adaptive Communication

Atta-ur-Rahman[1]

[1] *College of Computer Science and Information Technology (CCS&IT), Department of Computer Science, University of Dammam, Dammam, Kingdom of Saudi Arabia, Email: aaurrahman@uod.edu.sa*

Abstract: This is the era of information and communication technologies (ICT). In this era adaptive communication is playing a key-role. In this technique the available resources like power, code rate and modulation symbols are adapted intelligently to meet the users' constraints of high data rate and data integrity at the same time. In this regard, evolutionary algorithms are the best candidates to make such kind of intelligent decision. In this paper, Fuzzy Rule Base with Simulated Annealing (FRBSA) to adapt the power, code rate and modulation scheme in an orthogonal frequency division multiplexing (OFDM) environment is proposed. Simulated annealing takes care of adaptive power while adapting the code rate and modulation symbol is solely responsibility of the fuzzy rule base. The cases of fixed and adaptive communication are compared with existing well known techniques through computer simulations and results show the effectiveness of the proposed scheme.

Keywords: component; Simulated Annealing; OFDM; FRBS; BER; Adaptive Modulation and Coding

1. INTRODUCTION

Adaptive communication is getting a tremendous popularity over its static version due to the increasing demand of high data rates with sophisticated quality of service demands. This is because of the advent of distributed and cloud computing. Now the smartphones are not just phones but they are equipped with hundreds of applications apart from just telephony. That includes video conferencing, voice over IP (VOIP), thin-thick client architecture (where a part of computation is done on smartphone while rest is done on the backend server connected with a high data rate link) and much more.

Now the question is how to meet this huge data rate requirement with quality as another aspect. The answer is using the radio resources effectively among the subcarriers, subscribers or users so that everyone should be benefitted. Well, this is not that simple, since it is a complex optimization problem which is difficult, if not impossible, to solve by the traditional/ordinary optimization techniques. Moreover, such kind of techniques may be complex and time consuming for the solution that may not be acceptable for a real time environment.

On the other hands, soft-computing, evolutionary computing and their hybrid versions are becoming the promising candidates for the solution of above cited problem. These solutions may not be optimum but being sub-optimum they are still suitable in the real time system implementation and their hidden power to trace any nonlinear and complex dynamic problem. Namely, these algorithms are differential evolution (DE), genetic algorithms (GA), particle swarm optimization (PSO) and simulated annealing (SA) etc. A very helpful survey on adaptive communication techniques using soft-computing, evolutionary algorithms and hybrid intelligent techniques is given in [1] and [2]. The authors emphasizes that how above mentioned techniques alone and their hybridization may be helpful in optimum resource allocation in orthogonal frequency division multiplexing (OFDM) systems. This survey does not only cover the application of a fuzzy rule based system (FRBS) that helps choosing the radio resources dynamically according to the varying channel state information (CSI) but has a tendency to combat with the bit error rate. In this regard, combination of FRBS and evolutionary algorithms like GA, DE etc. has been investigated. In the literature, [3] and [4] proposed a GA based subcarrier and bit allocation technique for multi input multi output OFDM (MIMO-OFDM) systems. The complexity of the technique was shown quite low compared to its earlier variants. In [5], Atta-ur-Rahman et al proposed a very efficient adaptive coding and modulation scheme for digital video broadcast second generation (DVB-S2). That is a standard for satellite television broadcast and has a built-in support for adaptive coding a modulation. The modulation code (MODCOD) pair for the next transmission interval was chosen on the basis of a fuzzy rule based system by exploiting the clear-sky margin. It was shown through the simulations that with this support the satellite television (TV) services were available to the regions with high rain-fall. In the rule base design only practical modulations and codes were selected.

In another scheme, the authors proposed an FRBS assisted adaptive coding and modulation scheme for the OFDM systems where convolutional codes (CC) and product error correction codes (PECC) along with quadrature amplitude modulation (QAM) were investigated in this regard in [6] and [7] respectively. It was found out that CC and QAM combination performs better than PECC-QAM combination in terms of capacity, bit error rate and computational complexity.

A combination of water-filling algorithm in contrast to FRBS was investigated in [8] [9] and [10], for adaptive coding, modulation and power in OFDM systems. In this research the FRBS was used for adaptive coding and modulation while genetic algorithm and differential evolution helped in adaptive the power vector. The performance was compared with water-filling algorithm and proposed scheme with differential evolution outperformed genetic algorithm based scheme and bother outperformed compared to water-filling algorithm.

Gaussian Radial Basis Function Neural Network (GRBF-NN) and FRBS based real time adaptive power, coding and modulation scheme was proposed in [11]. In this technique the training and testing data set was produced with the help of differential evolution algorithm in which the FRBS was used as the fitness function. In this regard more than 50,000 examples were generated. Once the network was trained, it was ready for real time implementation. So by providing the channel state coefficients and the quality of service demand to the network, it instantly popped out the effective power vector along with the modulation code pairs that should be used for the next transmission interval to fulfill the bit error constraint along with the maximum achievable data rate.

In this paper, a fuzzy rule base and simulated annealing (FRBSA) assisted adaptive power, coding and modulation scheme is proposed which enhances the work done in [12]. Here the simulated annealing helps adapting the power vector while fuzzy rule base helps in adaptive the modulation symbol and code rate being used.

The remainder of this paper is organized as follows. In section 2, system model is introduced. Performance of coded modulation is presented in section 3. Section 4 formulates a constrained optimization problem. In section 5 a brief introduction to FRBS is given. Section 6 contains a brief introduction of simulated annealing algorithm; Section 7 contains the performance comparison of the scheme, while section 8 concludes the paper.

2. SYSTEM MODEL

For the experiment of the proposed idea OFDM equivalent baseband model with N number of subcarriers is assumed. Complete knowledge of channel state information on each subcarrier is known at receiver is assumed. Hence the equation 1 shows the frequency domain representation;

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

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.

The kth subcarrier channel coefficient can be written as;

$$h_k = \alpha_k e^{j\theta_k}; k = 1,2,......, N \tag{2}$$

where α_k is Rayleigh distributed random variable of kth subcarrier, and the phase θ_k is uniformly distributed over [0, 2π]. The proposed adaptation model is given in Fig-1.

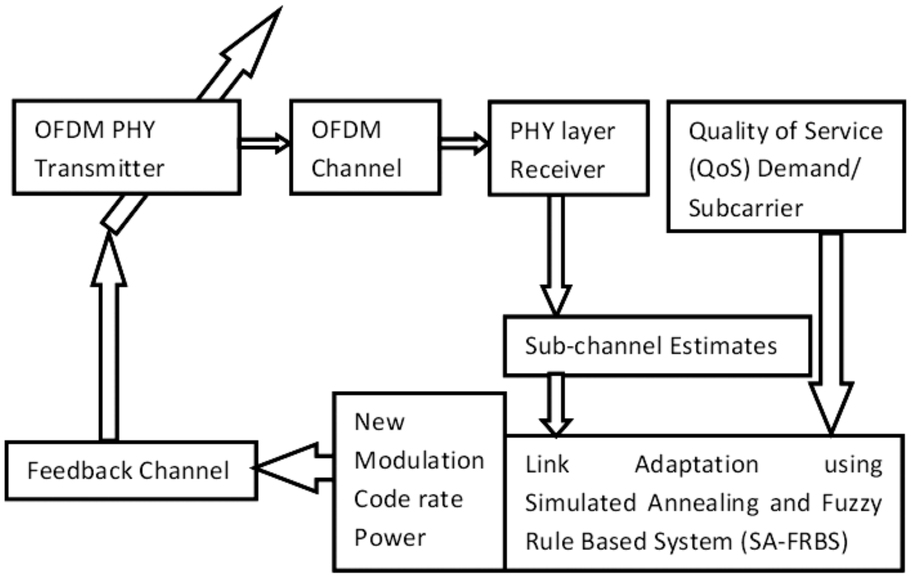

Figure 1: Brief diagram of proposed System

3. CODED MODULATION

This section highlights the bit error rate performance of different quadrature amplitude modulation (QAM) symbols and convolutional codes with different code rates as forward error correction codes (FECC). For these performances sequence of fig-2 is followed.

3.1. Modulation Symbol

For sake of testing of the proposed scheme, practical modulation scheme is used which is under use of IEEE 802.11n standard for WIFI. In this regard quadrature amplitude modulation is used where the modulation symbols 2, 4, 8, 16, 32, 64 and 128 are used that results in 1, 2, 3, 4, 5, 6 and 7 bits per symbol respectively. This can be given in a set M.

$$M=\{1,2,3,4,5,6,7\} \tag{3}$$

3.2. Code Rate

As far as code rates are concerned, we have utilized non recursive convolutional codes that are very practical in many of OFDM systems as forward error correction codes. The code rate used as listed in set C.

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

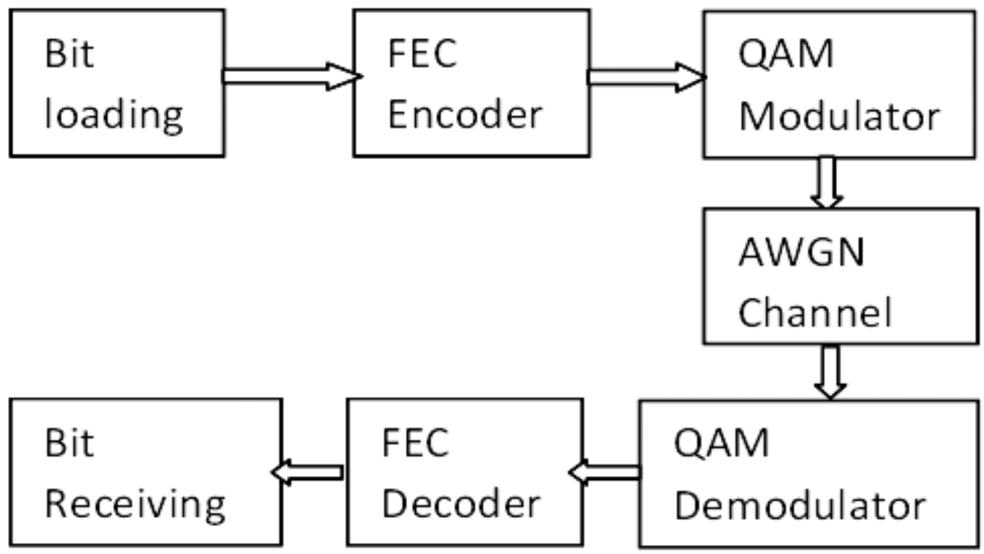

Figure 2: Brief diagram of simulations

From the discussion above the total number of modulation code pairs can be given as;

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

After this, bit error rate performance graphs of these modulation code pairs are drawn. Few of these graphs are depicted in the fig-3 and fig-4 below.

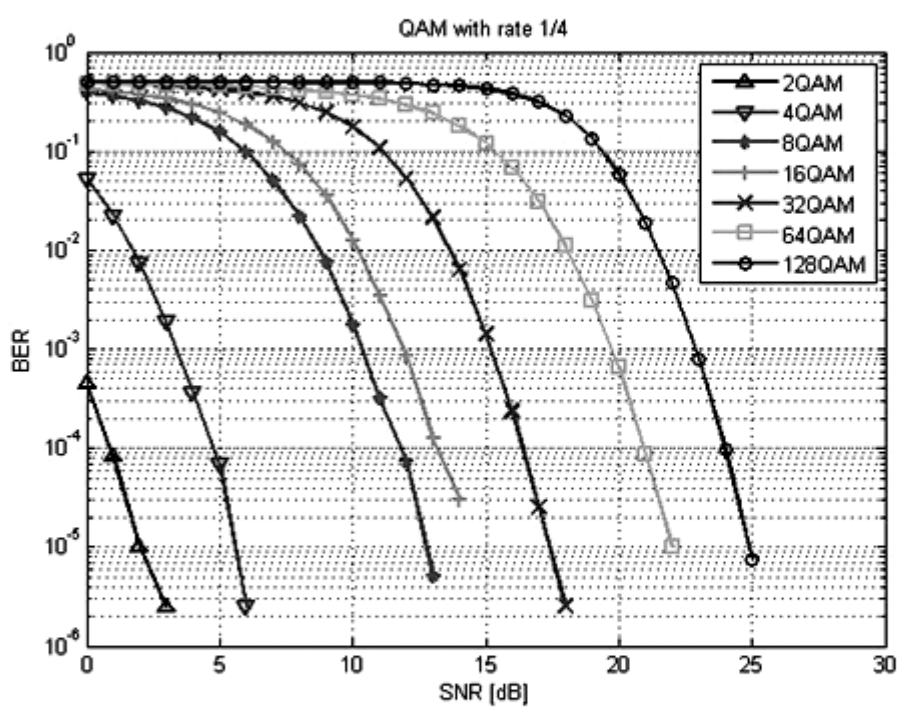

Figure 3: BER comparison of different QAM using rate 1/4 code

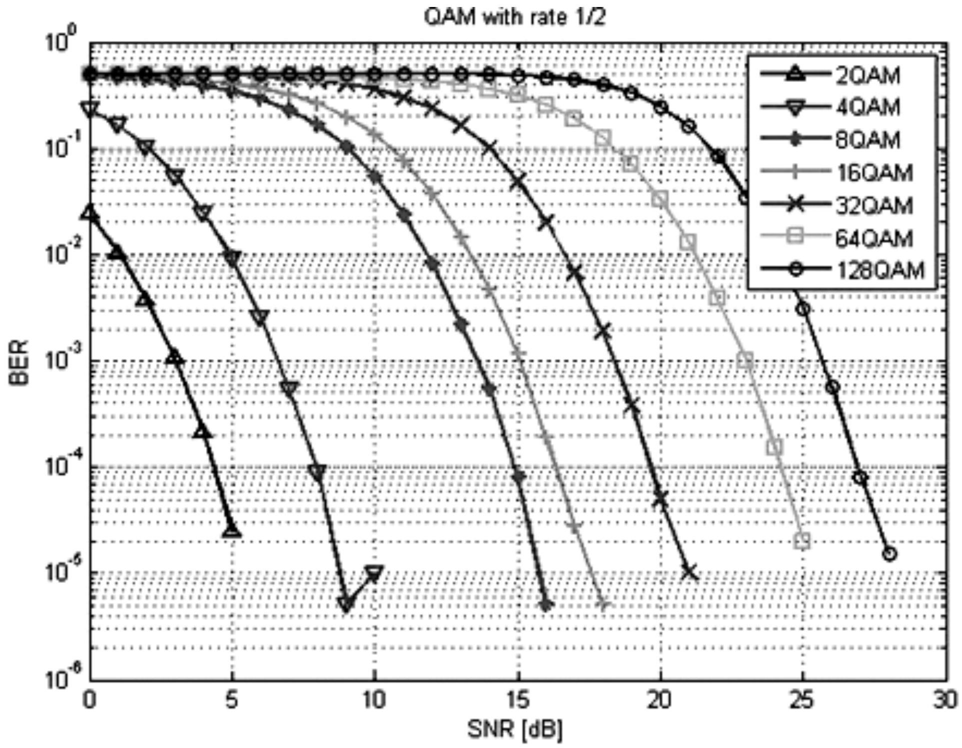

Figure 4: BER comparison of different QAM using rate 1/2 code

4. RATE OPTIMIZATION

Following constrained optimization problem is considered for sake of overall rate maximization of OFDM system.

$$\begin{aligned} &\max \quad R_{Total} = \frac{1}{N}\sum_{k=1}^{N} r_k \\ &\text{s.t,} \\ &BER_k \leq BER_{QoS_k} \\ &and \\ &P_{Total} = \sum_{k=1}^{N} p_k < P_T \end{aligned} \tag{6}$$

where $r_k = (\log_2(M))_k R_k$ is the bit rate of *k*th subcarrier which is product of code rate and bits/symbol. P_T is the total transmit power and BER_{QoS_k} is target BER that depends upon a specific quality of service (QoS) request or application requirement over *i*th subcarrier, while *N* represents the total number of subcarriers in the OFDM system.

5. FUZZY RULE BASE SYSTEM

This section is devoted to the construction of the fuzzy rule base that will help in adapting the code rate and modulation symbol upon provision of received signal to noise ratio and quality of service demand from the user. Following steps are involved in this regard.

5.1. Data Collection

In the previous section, we have plotted the bit error rate performance of different modulation schemes and convolutional code rates. So each graph in fig-3 and fig-4 represents a modulation-code pair. That provides an effective throughput (product or code rate and number of bits per symbol used in the modulation scheme) when a certain value of signal to noise ratio. Sot this is our fact sheet which narrates that in order to achieve a certain throughput under a certain bit error rate, which modulation code pair can be the candidate.

5.2. Rule Structure

The above explain fact sheet is actually our way to extract the rules from and complete the rule base. This will tell that provided a signal to noise ratio and target bit error rate which modulation code pair must be used. The rule can be seen as given below:

If (SNR=HIGH and BER=LOW) then MCP=HIGH

As we have divided the signal to noise ratio levels from L0 to L30 representing 0dB to 30dBs respectively. Similarly, there are certain number of candidate quality of service levels we call them Q1 to onward and similarly the modulation code pairs are numbered as P1, P2 and so on. Now if we consider the first input variable signal to noise ratio as x1 and second input variable which is quality of service demand as x2 and the output variable modulation code pair as y then the rule format can be given as below;

{IF (x_1 is L1 and x_2 is Q7) THEN y is P2}

Fig-5 shows the FRBS at a glance, that is, its input, output, inference engine and the other components used. Whereas, fig-6 shows the rule editor and the rule base of the fuzzy rule based system.

Following table-1 shows the brief description of different components of fuzzy rule base used. Design of the fuzzy rule base is carried out in MATLAB 7.0 using standard Fuzzy System Toolbox.

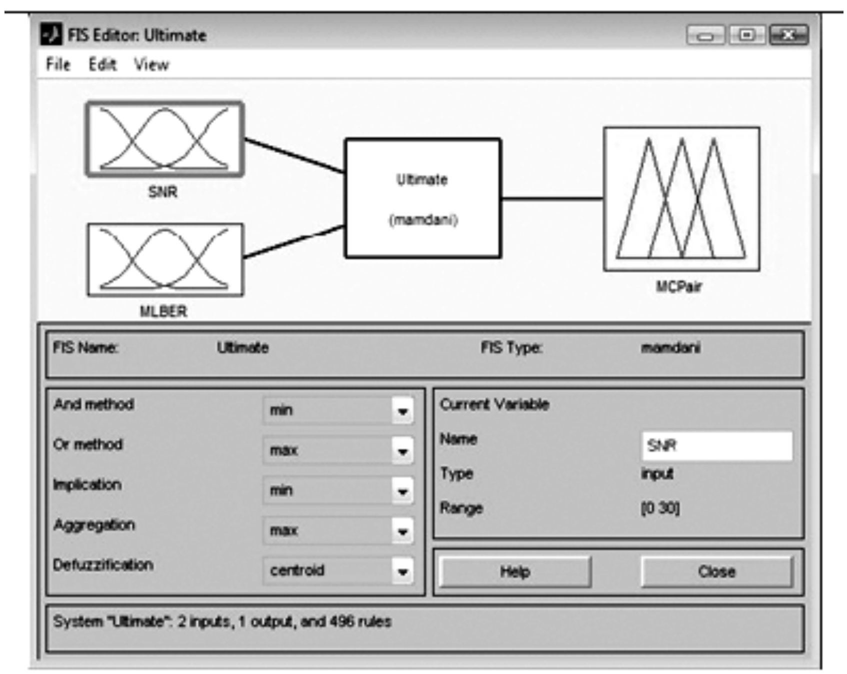

Figure 5: Components of FRBS

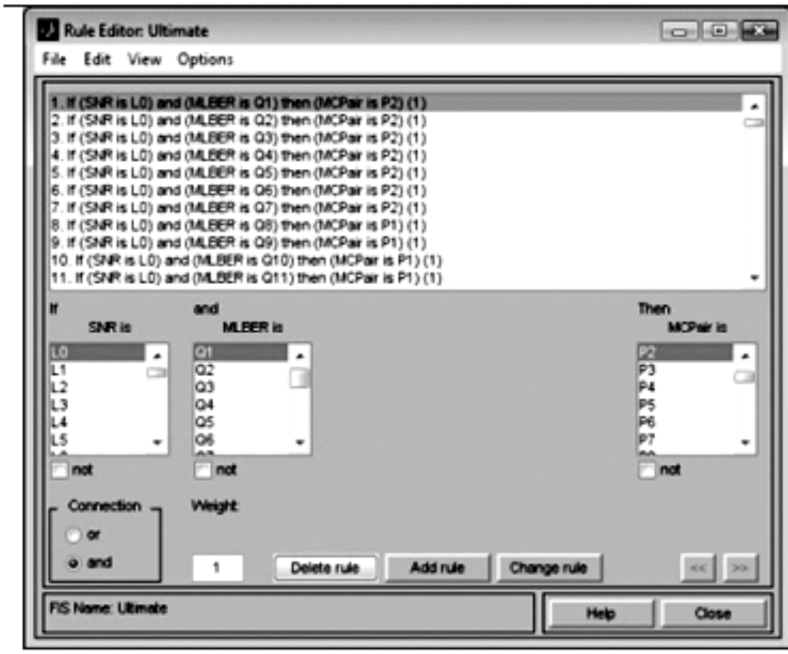

Figure 6: The Rule editor/rule base of FRBS

Table 1
Fuzzy Rule Base Parameters

Sr.	*Parameter*	*Value*
1	Number input variables	2
2	Number of output variables	1
3	First input variable	Signal to noise ratio (x1)
4	Second input variable	Quality of service demand (x2)
5	Output variable	Modulation code pair (Pi)
6	Range of first input variable	[0 to 30]dB
7	Range of second input variable	[Q0 to Q16]
8	Range of output variable	P1 to P28
9	Fuzzifier	Standard Triangular Fuzzifier with AND as MIN and OR as MAX
10	Inference Engine	Mumdani
11	Total number of rules	496
12	De-fuzzifier	Center average defuzzifier (CAD)
13	Is rule base complete?	Yes

6. SIMULATED ANNEALING ALGORIHTM

Simulated annealing is one of the famous global evolutionary optimization techniques. It combines the concepts of statistical mechanics and the traditional combinatorial optimization. It was proposed by Kirkpatrick et al [13].

In the proposed scheme, we are intended to use if for the selection of optimum power vector to be used for power transmission over different subcarriers during the next transmission interval. Like other evolutionary algorithms like GA and DE, it also demands a fitness function. Here in this scenario that fitness function is given in fig-8.

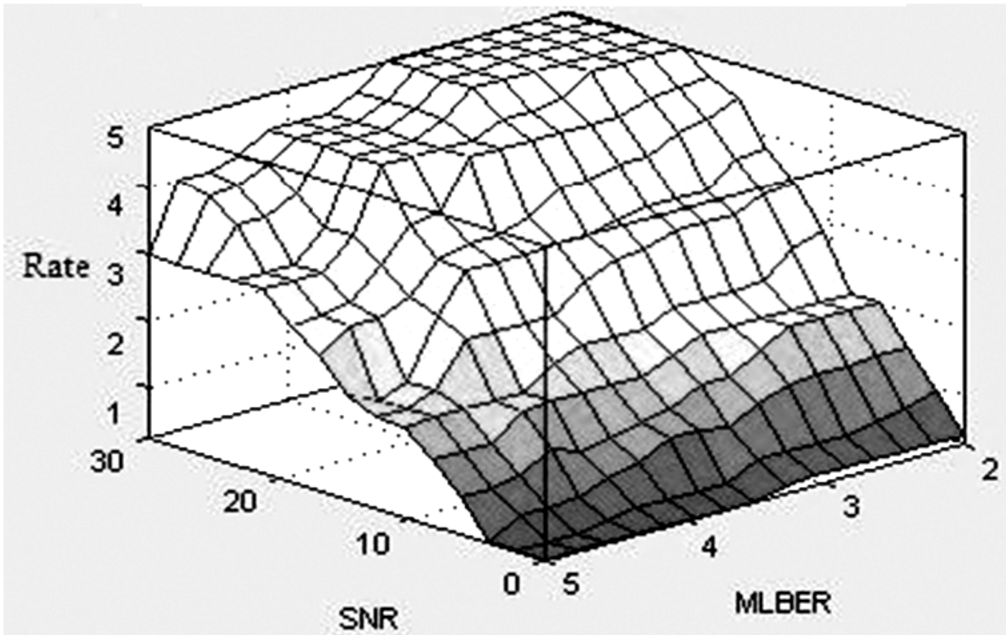

Figure 7: Rule surface

That can be expressed as;

$$R = FRBS(RSNR, QoS) \tag{8}$$

This means the rate (to be maximized) is a function of received signal to noise ratio and quality of service demand from the users. Then the adequate rate will be calculated by the proposed fuzzy rule based system. It can be stated as "given as specific quality of service demand and a received SNR vector, which modulation code pair can produce the highest throughput."

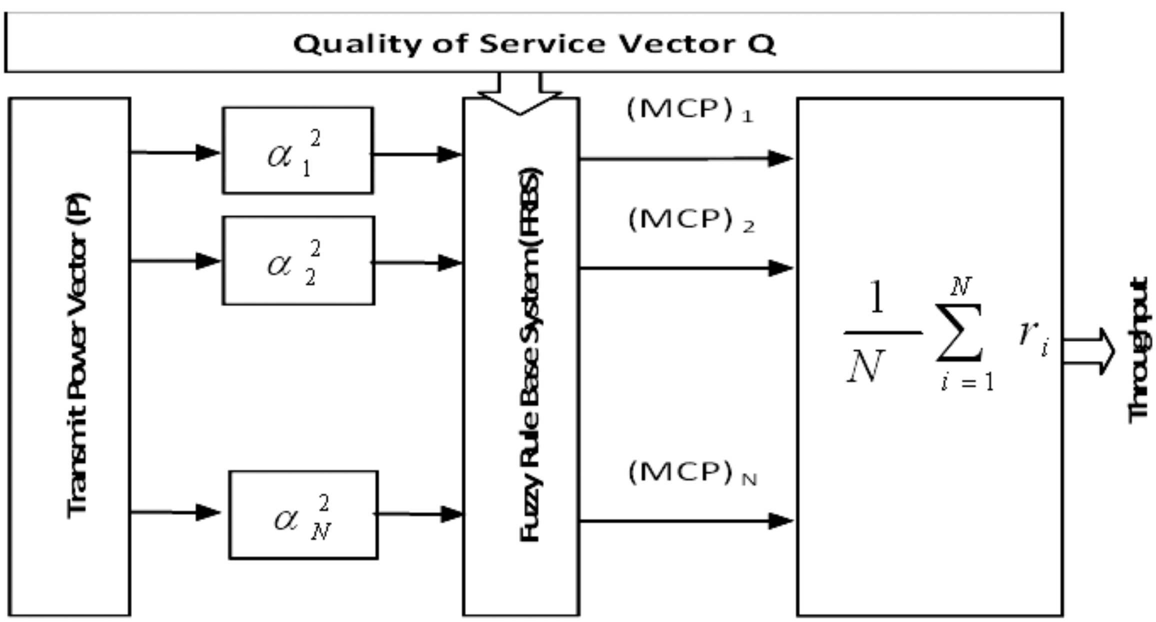

Figure 8: The fitness function

8. RESULTS

In this section proposed scheme is compared with other schemes like the fixed modulation and coding. Table-2 contains the simulation parameters in this regard.

Table 2
The Simulation Parameters

Sr.	*Parameter*	*Value*
1	Number of Subcarriers N	1024
2	Fitness Function for SA	Fuzzy Rule Base System Fig-6
3	SA iterations	30
4	Channel considered for simulation	IEEE 802.11n indoor channel (WIFI)
5	Channel Coefficients range	[0.1-0.4]
6	Quality of Service (QoS)	10e-2,10e-3,10e-4 and 10e-5
7	Adaptive Criterion	FRBSA
8	Parameters being adapted	Code rate, Modulation and power
9	Minimum throughput (Modulation Code Product)	1bit/s/Hz
10	Maximum throughput MCP	6bits/s/Hz

In the simulation result, extensive comparisons are made to truly investigate the proposed scheme. In this regard the performance of fuzzy rule base and simulated annealing (FRBSA) assisted adaptive power, coding and modulation (APCM), in terms of data rate is shown in fig-9 to fig-12 for different cases of target bit error rate.

For example, the target bit error rate was set to 10^-2 in fig-9 which is a very loose constraint to meet. This type of bit error rate may be demanded for the applications like speech and video. In which if some frames may be lost even then the contents are understandable. This make the application less sensitive in terms of bit error rate or quality of service demand from the designated used. At a signal to noise ratio of 26dBs, FRBSA provides a throughput of 5.5bits/s/Hz while the fixed coding and modulation scheme reaches to 4.45bits/s/Hz. This is a significant difference that can be observed over different values of signal to noise ratio.

Now the target bit error rate was set to 10^-3 in fig-10. At a signal to noise ratio of 25dBs, FRBSA provides a throughput of 5.1bits/s/Hz while the fixed coding and modulation scheme reaches to 3.5bits/s/Hz. This is a significant difference that can be observed over different values of signal to noise ratio.

Now the target bit error rate was set to 10^-4 in fig-11. At a signal to noise ratio of 25dBs, FRBSA provides a throughput of 4.5bits/s/Hz while the fixed coding and modulation scheme reaches to 3.0bits/s/Hz. This is a significant difference that can be observed over different values of signal to noise ratio.

Now the target bit error rate was set to 10^-5 in fig-12 which is a very tight constraint to meet. At a signal to noise ratio of 25dBs, FRBSA provides a throughput of 2.6bits/s/Hz while the fixed coding and modulation scheme reaches to 1.7bits/s/Hz. This is a significant difference that can be observed over different values of signal to noise ratio. This type of bit error rate may be demanded for the sensitive applications like text etc.

From the above figures it is apparent that the signal to noise ratio is inversely proportional to the bit error rate which is a rule of thumb.

Table 3
Comparison of proposed scheme with fixed coding and modulation at SNR=25dB

Sr.	*Target Bit Error Rate*	*Throughput [bits/s/Hz] of FRBSA based APCM*	*Throughput [bits/s/Hz] of Fixed coding modulation*
1	10^-2	5.5	4.45
2	10^-3	5.1	3.5
3	10^-4	4.5	3.0
4	10^-5	2.6	1.7

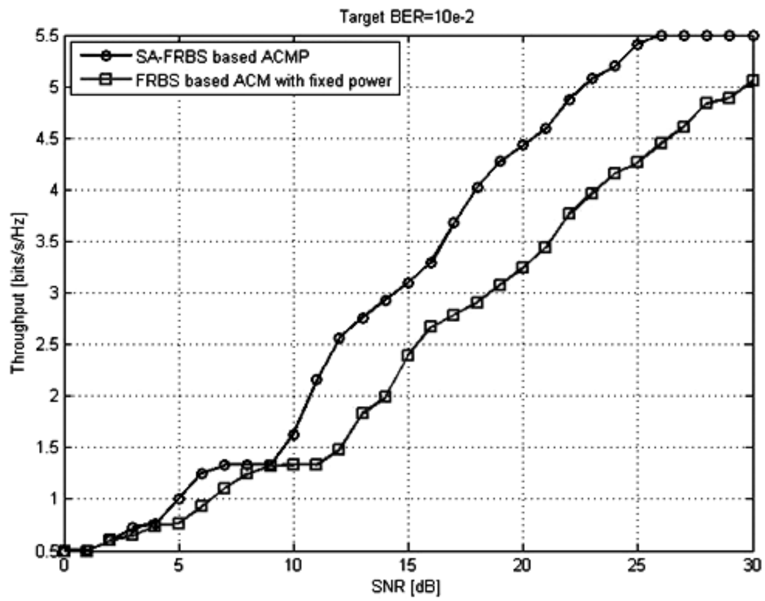

Figure 9: Comparison of proposed scheme with QoS=10e-2 per subcarrier

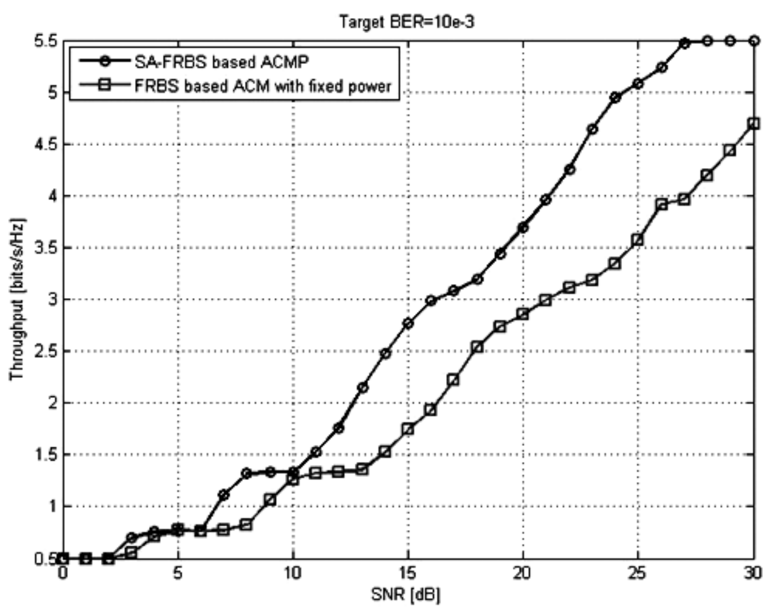

Figure 10: Comparison of proposed scheme with QoS=10e-3 per subcarrier

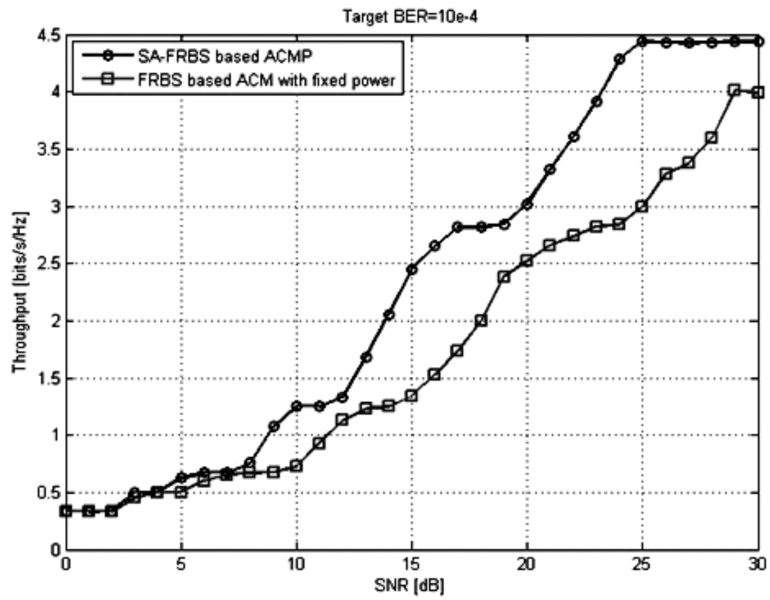

Figure 11: Comparison of proposed schemes with QoS=10e-4 per subcarrier

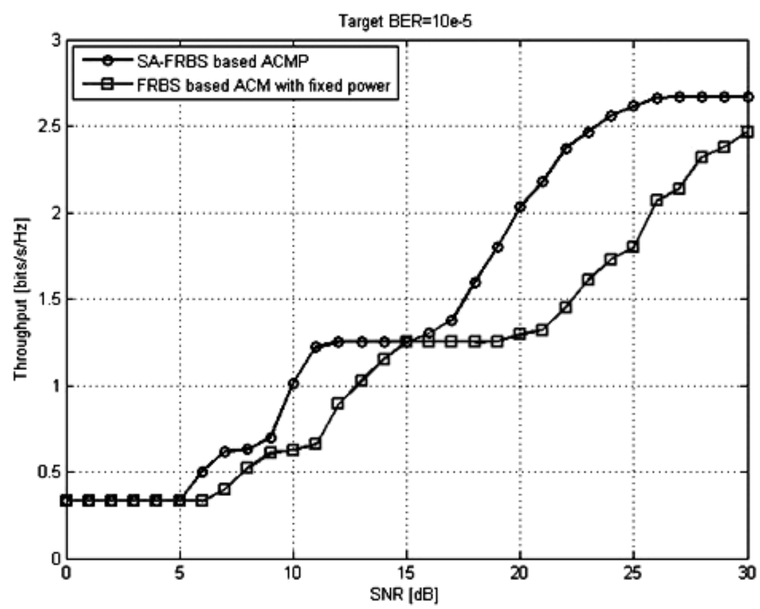

Figure 12: Comparison of proposed schemes with QoS=10e-5 per subcarrier

Now the performance of the proposed scheme is compared with different target bit error rate like 10^-2 t0 10^-5 respectively and this is shown in the fig-13. For bit error rate 10^-2 to 10^-4 the performance of the proposed scheme is marvelous in a way that even at 15dB signal to noise ratio the throughput is considerable. However, for target bit error 10^-5 the throughput deteriorates. This is understandable because 10^-5 means only one bit can be erroneous during transmission of one hundred thousand bits. Fig-14 provides an upper and lower bound on the performance of the proposed FRBSA technique. Over here, random quality of service demands were generated per subcarrier which is a more practical scenario. In this scenario the average throughput reaches to 4bits/s/Hz for a 30dB signal to noise ratio. Which is exactly and average of 5.5bits/s/Hz (a case of 10^-2 as target bit error rate) and 2.5bits/s/Hz (a case of 10^- 5 as target bit error rate) for the proposed FRBSA scheme. This can be seen in fig-11-12 and well as in table-2.

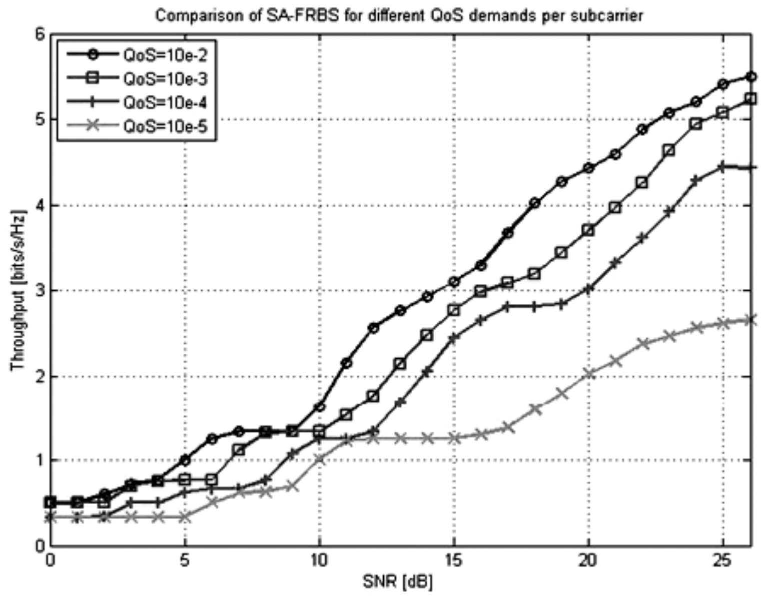

Figure 13: Comparison of proposed scheme for different target BER

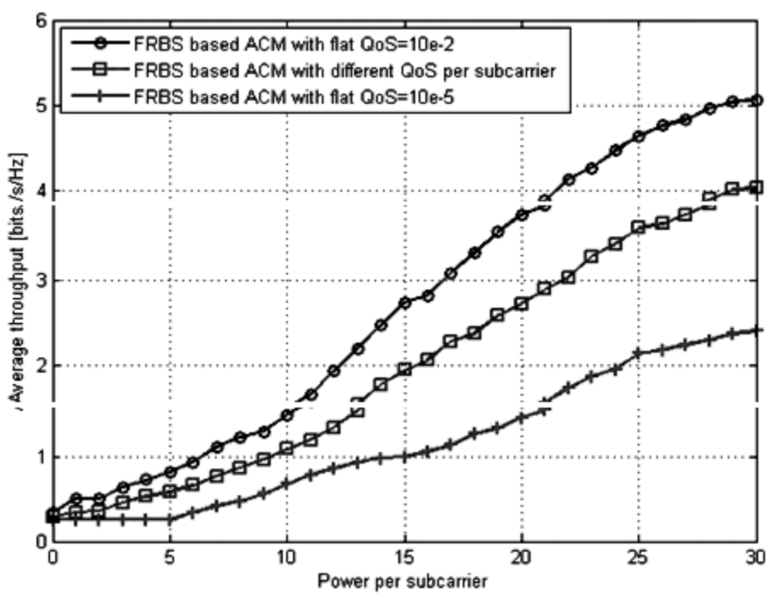

Figure 14: Upper and Lower bounds on performance of the proposed scheme

9. CONCLUSIONS

In this paper, fuzzy rule base with simulated annealing (FRBSA) technique for adaptive power, coding and Modulation (APCM) in orthogonal frequency division multiplexing (OFDM) scenario is proposed. IEEE 802.11n which is IEEE standard for wireless indoor channel environment is taken as system model for the experiment of the proposed scheme. The scheme has been investigated for different bit error rate constraints and it is found that the communication survives for even very tight bit error rate constraint with a reasonable throughput. The scheme was compared with the fixed communication system case and at many situations the gain was 10dBs. Upper and lower bound on the performance of the proposed scheme as also computed in the computer simulations.

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