A GA-FRBS based Rate Enhancement Scheme for OFDM based Hyperlans

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***Abstract*— Adaptive communication is need and feature of every current communication system. In this technique the transmission parameters are adapted in such a way that overall system throughput may be enhanced while satisfying certain number of constraints. In short this is a constrained optimization problem. In this paper a similar constrained optimization problem is focused and solved by making certain parameters adaptive that are code rate, modulation scheme and transmit power in a multicarrier OFDM environment. For adapting the said parameters a Fuzzy Rule Base System (FRBS) is used in conjunction with Genetic Algorithm (GA). So FRBS and GA suggest the optimum code rate, modulation symbol and power with respect to the channel state information (CSI) given at any instance that can maximize the throughput while satisfying constraints like power and bit error rate (BER). Product codes and Quadrature Amplitude Modulation (QAM) are used as coding and modulation schemes respectively. Simulation results show the significance of proposed scheme.**

Keywords-component; GA, OFDM; FRBS; BER; ACM, Modulation Code Pair, Product Codes

I. INTRODUCTION

Adaptive communication is the most prominent feature of many 3rd Generation (3G) and 4th Generation (4G) systems. In this regard, transmitter adequately adapts the various transmission parameters like code rate, modulation size and power etc with respect to the varying channel state information (CSI). In this way, if channel is having poor conditions then a FEC with relatively lower code rate and a smaller modulation symbol like binary phase shift keying (BPSK) can be used with relatively more power. Similarly, if channel conditions are good a comparatively high code rate or even no coding can be used in contrast to a high modulation symbol like 64 QAM with relatively moderate power. Orthogonal Frequency Division Multiplexing (OFDM) systems have been used in almost all recent wireless standards like WIFI [1] and WiMAX etc [2]. In OFDM a high data stream is divided into many relatively low data streams by taking Inverse Fast Fourier Transform (IFFT), and then these streams are modulated over orthogonal subcarriers. This arrangement helps a lot again frequency selectivity. The orthognality of subcarriers and addition of a suitable cyclic prefix (CP) causes great reduction in inter symbol interference (ISI).

In literature many adaptive power and bit loading techniques have been proposed. The idea of adaptive modulation is no new however consideration of a practical channel code and other parameters is quite recent approach. Kallet, in 1989 [3], proposed adaptive modulation for OFDM systems. Chow et al [4] investigated same technique for Gaussian slowly varying dispersive channel and found it quite applicable. The same idea of adaptive modulation for wideband radio channel was investigated by Cyzlwik in 1996 [5]. In 2010, Sastry et al [6] proposed adaptive modulation using Fuzzy Logic interface.

A turbo coded adaptive modulation scheme was proposed by Hanzo et al [7], where there signal to noise ratio (SNR) thresholds were used for adapting modulation. Coded bit and power loading problem for single antenna OFDM systems, was addressed by Li et al, Low Density Parity Check Codes (LDPC) were examined [8] originally motivated by [9]. A common observation in above cited work was that in these systems one of two parameters was fixed while other was adaptive. That is either modulation was adaptive with a fixed channel code [7] [8] [9] or channel code was adaptive and modulation was fixed [10]. A Genetic Algorithm (GA) based adaptive resource allocation scheme was proposed by Reddy [11], 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.

In this paper, an adaptive coding and modulation scheme is proposed in which all the parameters are adapted using a fuzzy rule base system. FRBS suggests which modulation code pair (MCP) should be used, depending upon the channel conditions while GA suggests the power so that overall throughput of the OFDM system may be maximized.

Rest of the paper is organized as follows. System model is given in section 2; section 3 contains a brief introduction of Multilevel Codes and their decoding; coded modulation and simulations for various modulation code pairs in given in section 4; section 5 contains rate optimization criteria and cost function to be optimized, in section 6 Fuzzy Rule Base System creation steps and parameters are explained, in section 7 brief description of Genetic Algorithm is given; simulation results of proposed scheme are depicted in section 8 while section 9 concludes the paper.

II. SYSTEM MODEL

The system model considered is OFDM equivalent baseband model with N number of subcarriers. It is assumed that complete channel state information (CSI) is known at both transmitter and receiver. The frequency domain representation of system is given by

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

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where y_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 *k*th 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 *k*th subcarrier can be expressed as:

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

where α_k is Rayleigh distributed random variable of *k*th subcarrier, and the phase θ_k is uniformly distributed over $[0, 2\pi]$.

III. Product Codes and Modified Iterative Decoding Algorithm

A. Product Codes

Product codes are serially concatenated codes that were firstly presented by Elias in 1954 [12]. The concept of Product codes is quite simple as well as powerful, where much shorter constituent block codes are used instead of one long block code. Basically these are matrix codes where rows are encoded by one block code while columns are encoded by another block code. This arrangement enhances their error correction capability since errors are corrected row-wise as well as column-wise. Also these codes are burst error correcting codes since a row-wise burst can easily be corrected column-wise and vice versa. Since burst error in rows will become single error for column code and vice versa.

Consider two linear block codes $\mathbf{A_1}$ and $\mathbf{A_2}$ with parameters $[n_1, k_1, d_1]$ and $[n_2, k_2, d_2]$ respectively, where n_i, k_i and $d_i ; i = 1,2$ are the length, dimension and minimum Hamming distance $d_{\min}$ of the code $\mathbf{A}_i \ (i = 1,2)$ respectively. Code $\mathbf{A}_1$ will be used as row code while $\mathbf{A}_2$ will be used as column code. The rates of individual codes are R_1 and R_2 respectively given by,

$$R_i = \frac{k_i}{n_i}, i = 1,2 \qquad (3)$$

The product code $\mathbf{\Phi}$ can be obtained by codes $\mathbf{A}_i, i = 1,2$ in the following manner.

- Place $k_1 \times k_2$ information bits in an array of k_2 rows and k_1 columns
- Encode k_2 rows using code $\mathbf{A}_1$, which will result in an array of $k_2 \times n_1$
- Now encode n_1 columns using code $\mathbf{A}_2$, which will result in $n_2 \times n_1$ product code.

The resultant product code $\mathbf{\Phi}$ has the parameters $[n_1 n_2, k_1 k_2, d_1 d_2]$ and the rate will be $R_1 R_2$. In this way long block codes can be constructed using much shorter constituent block codes. This can be written as;

$$\mathbf{\Phi} = \mathbf{A}_1^{'} \cap \mathbf{A}_2^{'} \qquad (4)$$

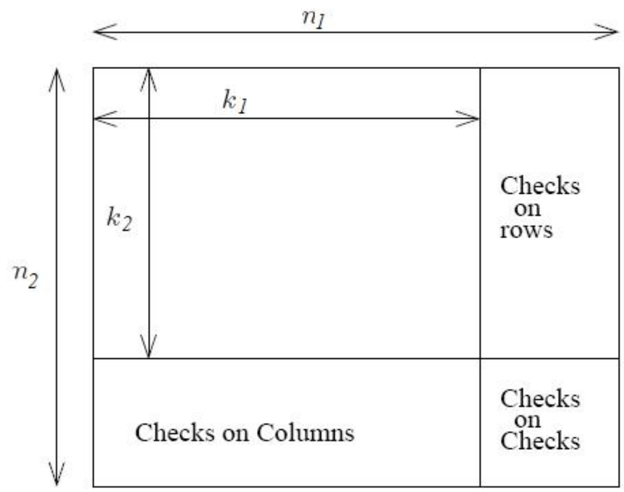

Figure 1. Structure of the Product code

B. Modified Iterative Decoding Algorithm

Iterative decoding algorithm (IDA) for product codes was originally presented by [10] in his Doctoral thesis that is based upon List Decoding also designated as Maximum Likelihood (ML) decoding of product codes. ML decoding is an optimum decoding with an exponential complexity. The iterative decoder was proposed to reduce the complexity of ML decoding, but yet it exhibits a huge complexity. Modified Iterative Decoding Algorithm (MIDA) is modification of IDA in which complexity of basic algorithm is significantly reduced by using concept of Syndrome Decoding to overcome the search space radius. The decoder is consisted of two sub-decoders namely row-decoder and column-decoder both placed in succession. Interested readers may visit original paper by the same author [12].

IV. Coded Modulation

A. Coding Scheme

Coding schemes used for this framework are set of product codes. Since product codes are matrix codes, where rows contain one code and column contains another code. The set of row codes and column codes used in this paper are listed in table1. All of these codes are BCH codes. So set of code is initially consisted of four different product codes. That is

$$C = \{C_i\}; 1 \le i \le 8 \qquad (5)$$

The error correcting capability of a block code can be found by the following equation.

$$t = \left\lfloor \frac{d_{\min} - 1}{2} \right\rfloor \qquad (6)$$

TABLE I. CODING PARAMETER

Sr.	Row Code	Column Code	Product Code	Code rate	Error Correcting Capability
C1	[63,63,1]	[63,63,1]	[3969,3969,1]	1	0
C2	[63,57,3]	[63,63,1]	[3969,3591,3]	0.9	1
C3	[63,51,5]	[63,63,1]	[3969,3213,5]	0.8	2
C4	[63,36,11]	[63,63,1]	[3969,2268,11]	0.57	5
C5	[63,63,1]	[63,57,3]	[3969,3591,3]	0.9	1
C6	[63,57,3]	[63,57,3]	[3969,3249,9]	0.82	4
C7	[63,51,5]	[63,57,3]	[3969,2907,15]	0.73	7
C8	[63,36,11]	[63,57,3]	[3969,2052,33]	0.51	16

In first four codes that is C1 to C4, column code is considered as rate 1 that is [63, 63, 1] while in last four codes that is C5 to C8 [63, 57, 3] is considered as column code.

B. Modulation Scheme

The modulation scheme used for this experiment is Quadrature Amplitude Modulation (QAM) which is recommended by many OFDM standards. Following set of modulation symbols is used. That is

$$M = \{2,4,8,16,32,64,128\} \quad (7)$$

So with these coding and modulation sets we have 28 possible modulation code pairs (MCP) by a Cartesian product of the sets C and M.

$$P = C \text{x} M = \{(c_i, m_j); \forall c_i \in C, \forall m_j \in M\} \quad (8)$$

All of the possible combinations of modulation code pairs are obtained in equ-8. Some of these pairs are shown in fig-3 and 4 by using simulation model given in fig-2.

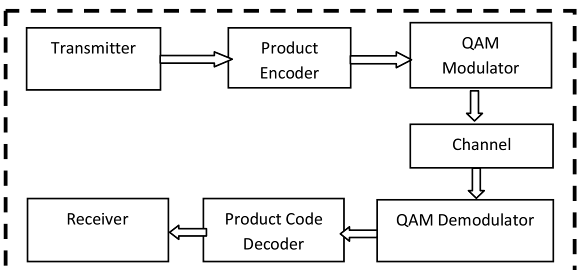

Figure 2. System model for simulation

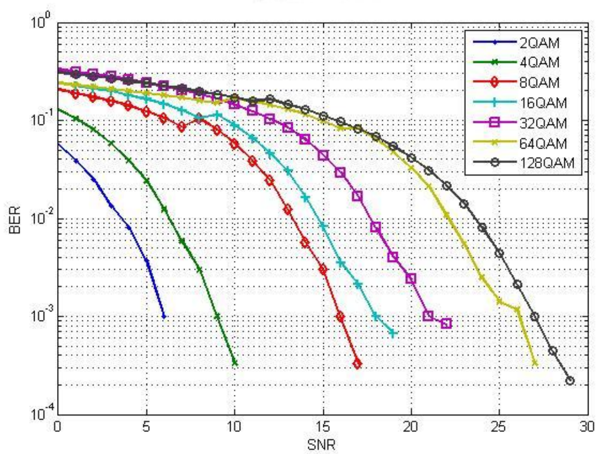

Figure 3: Performance of different QAM schemes using C1 product code

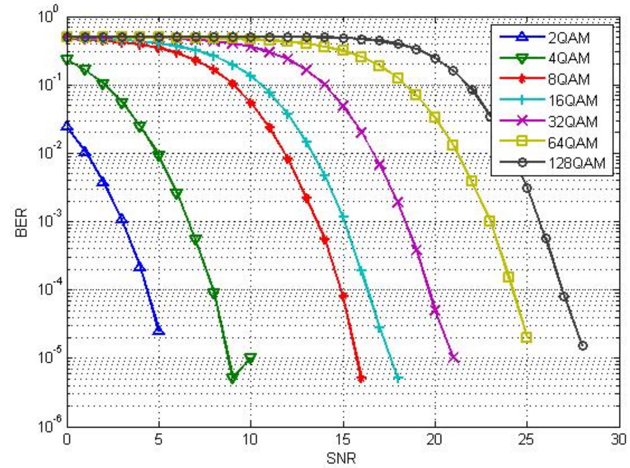

Figure 4: Performance of different QAM schemes using C6 product code

V. RATE OPTIMIZATION

In order to maximize the rate for OFDM system following constrained optimization problem is considered.

$$\max \quad R_{Total} = R \log_2(M)$$

$$\text{s.t,} \quad (9)$$

$$BER_{Total} \le BER_T \text{ and } P_{Total} = \sum_{i=1}^{N} p_i < P_T$$

Where R is the rate of product code used from set C and M is the size of modulation symbol used from set M. P_T is the available transmit power and p_i is power transmitted per subcarrier. BER_T is target BER that depends upon a specific quality of service (QoS) request or application demand. The available QoS are $BER_T = 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}$ while N is total number of subcarriers in OFDM system. The above cost function is optimized by the proposed Fuzzy Rule Base System. System model is shown in fig-5.

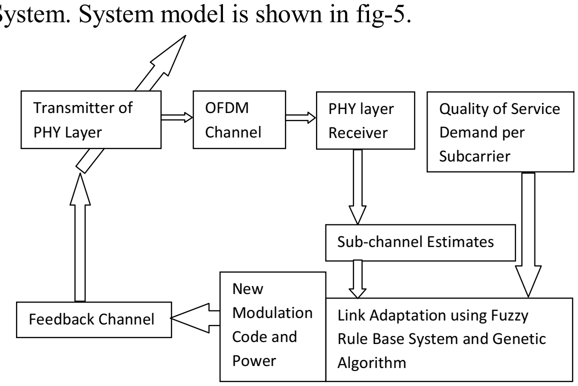

Figure 5. Proposed system model for adapting parameters

VI. FUZZY RULE BASE SYSTEM

A fuzzy rule base system (FRBS) is proposed, which is capable of deciding the best modulation code pair (MCP) for the next transmission, based upon the heuristics. Fuzzy logic is recommended for the situations that are vague, ambiguous, noisy or missing certain information. Also fuzzy systems are easy to implement in hardware. There are many ways to build a Fuzzy Rule Base System, we have used *table lookup scheme for this purpose*.

A. Obtaining Graphs

Graphs for different combinations of Codes and Modulation schemes are obtained few of them are plotted in fig-3 and 4.

B. Data Acquisition

Data is obtained from the graphs in terms of input/output (IO) pairs. This is taken by drawing the horizontal lines for various BER and then points of intersection of these lines with the curves are noted and stored in table shown in fig-6.

C. Rule Formulation

Rules for each 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.

D. 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 two different MCP namely, [32, C3] and [32, C4]. Now [32, C3] is best since its throughput is 5x0.8=4 b/s/Hz while others have 5x0.57=2.58 respectively. Similarly, sometime there could be two different pairs with same throughput like [32,C3] and [16,C1] both have same throughput that is 4 b/s/Hz, then [16,C1] will be chosen since it exhibits less processing cost.

E. 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. Since if a modulation code pair performs for lower SNR, then it can easily sustain in higher SNR situations etc.

F. Fuzzy Rule Base Creation

Using the Lookup table in above phase Fuzzy Rule Base is created using Fuzzy Logic Toolbox in MATLAB. A detail of FRBS creation can be found in [14] by the same authors.

G. Components of Fuzzy Rule Base System

i. Lookup table

This table shows the facts extracted for simulated performance of different codes and modulation pairs in previous section. It can be stated as "for a given received SNR and a fixed QoS, which MCP maximizes the throughput". Received signal to noise ratio is expressed in level 1 to level 9 and Quality of Service are given like poor, med, good and high that is $10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ respectively. The input-output pairs needed for design of FRBS are of the form;

$$(x_1^p, x_2^p; y^p); p = 1, 2, 3.......M \qquad (10)$$

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

{IF (x_1 is Good and x_2 is L7) THEN y is P15}

SNR-->>				
L1	P1	P10	P18	P18
L2	P2	P11	P19	P10
L3	P3	P12	P2	P11
L4	P4	P13	P13	P2
L5	P5	P14	P20	P22
L6	P6	P15	P21	P14
L7	P7	P16	P15	P23
L8	P8	P17	P16	P24
L9	P9	P9	P9	P25
	Poor	Med	Good	High
	QoS-->>			

Figure 6. Lookup Table for FRBS Creation

ii. Fuzzy Sets

Sufficient numbers of fuzzy sets are used to cover the input output spaces. There are two input variables *average 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 $10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ etc while the range of fuzzy variable should be equally spaced and quantifiable. So to get this, following operation is done first.

$$\begin{aligned} MLBER &= -\log(BER); BER = 10^{-q} \\ MLBER &= -\log(10^{-q}) = q \end{aligned} \qquad (11)$$

There is one output variable for modulation code pair MCP. There are nine, four and eighteen fuzzy sets used for the variables SNR, MLBER and MCP, respectively.

iii. Fuzzifier

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

iv. Rule Base

Rule base contains rules against all the IO pairs. As there are nine sets (L1 to L9) for first input variable named SNR and about four sets (low, medium, good and high) for input variable MLBER. Hence there are 36 rules in rule base. Rule base is complete in a sense that rules are defined for all possible combinations of input spaces.

v. Inference Engine

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

vi. De-Fuzzifier

Standard Center Average Defuzzifier (CAD) is used for defuzzification.

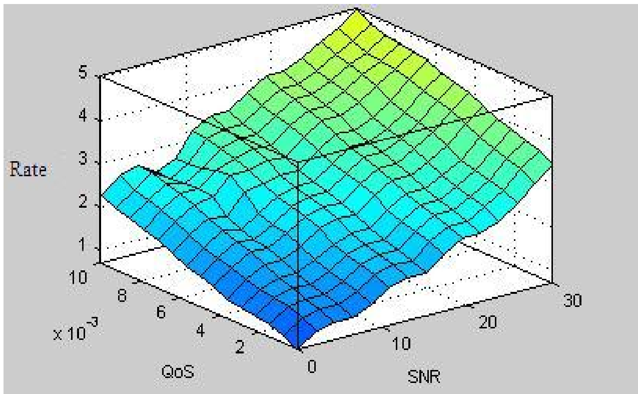

Figure 7. Rule surface of FRBS

Fig-7 shows the rule surface that shows that by varying SNR and QoS the throughput is varied. For the highest value of SNR and lowest value of QoS, throughput of the system approaches to 5bits/s/Hz.

VII. 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.

Fig-8 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;

$$R = FRBS(RSNR, QoS) \qquad (13)$$

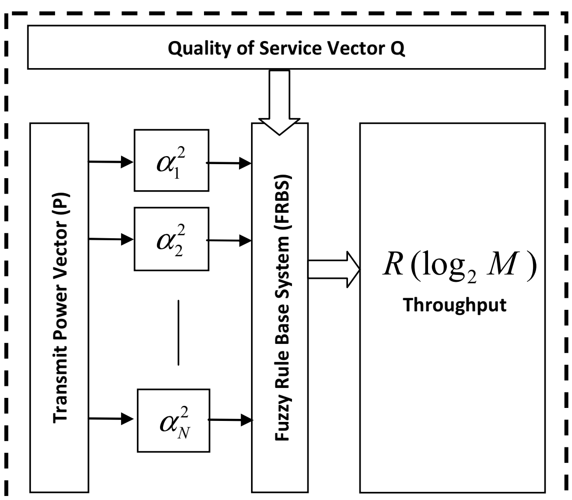

Figure 8. Fitness Block

The algorithm used is described below in fig-10.

Algorithm

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

Figure 9. The Genetic Algorithm

VIII. RESULTS

In this section proposed scheme is compared with the other adaptive techniques and HYPERLAN/2 standard. Simulation parameters are enlisted in table-II. In fig-10, proposed scheme is compared for various quality of service (QoS) like average BER=10e-1, 10e-2, 10e-3 and 10e-4 with fixed transmit power. In this way QoS was fixed initially then depending upon the received signal to noise ratio (SNR), most appropriate modulation code pair (MCP) was chosen using Fuzzy Rule Base System (FRBS), then the product of modulation rate and code rate so called modulation-code-product (throughput) is plotted. In fig-11, proposed scheme plotted for various QoS but with adaptive power. A significance difference can be seen between fixed and adaptive powers. In fig-12 proposed scheme is compared with the adaptive coding and modulation scheme proposed by Al-Askary in this PhD dissertation [10] in which the adaptation was based upon SNR thresholds. As simulation results reveal, proposed scheme profoundly performs better than that of proposed by Al-Askary as well as HYPERLAN/2 standard.

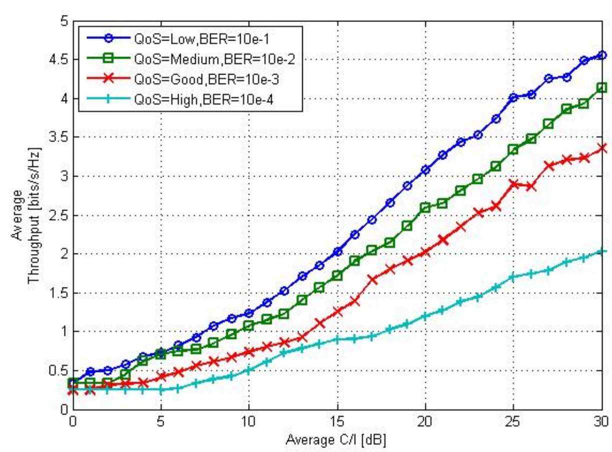

Figure 11. Comparison of proposed scheme for various QoS in a HYPERLAN/2 environment with fixed power

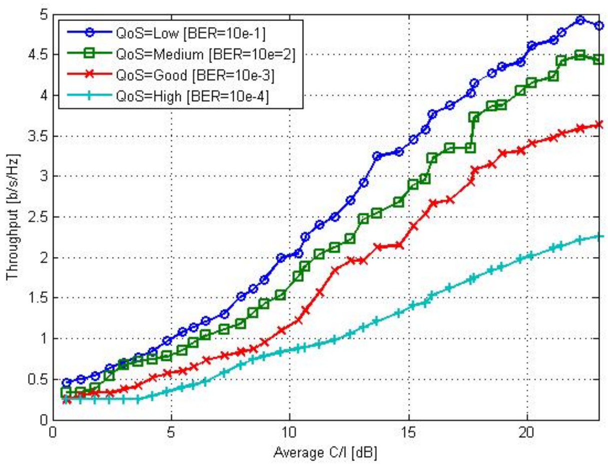

Figure 12. Comparison of proposed scheme for various QoS in a HYPERLAN/2 environment with GA based adaptive power

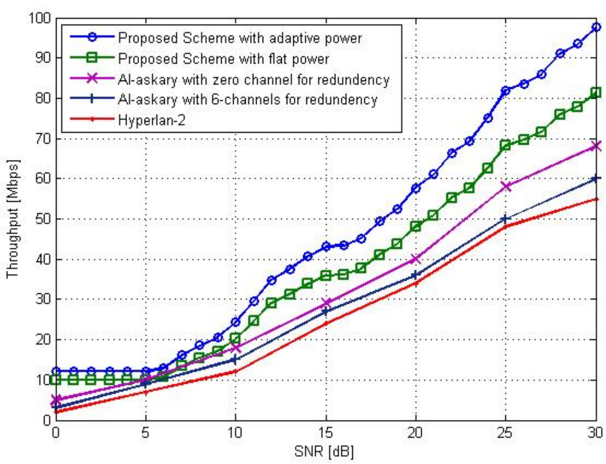

Figure 10. Comparison of proposed scheme with different schemes

TABLE II. SIMULATION PARAMETERS

Sr	Parameter name	Value
1	Coding Schemes	Product Code
2	Code rates	1, 0.9, 0.8, 0.57
3	Modulation Schemes	2, 4, 8, 16, 32, 64, 128 QAM
4	Bits/symbols in modulation	1, 2, 3, 4, 5, 6, 7
5	Total MCPs	4x7=28
5	OFDM Standard used	HYPERLAN/2
6	Number of subchannel	63
7	Minimum throughput MCP	0.57x1=0.57bits/s/Hz
8	Maximum throughput MCP	1x7=7bits/s/Hz
9	Adaptation	Modulation, code and power
10	Adaptation Criteria	GA, Fuzzy Rule Base System

IX. CONCLUSIONS

An adaptive coding, modulation and power scheme is proposed using Fuzzy Rule Base System and Genetic Algorithm, where product codes are utilized with QAM. Fuzzy Systems are suited for the situations that are vague and missing certain information, also once the Fuzzy Rule Base System is created can easily be implemented in hardware and it is suitable for real time systems. The proposed scheme was tested for OFDM HYPERLAN/2 standard and compared to a similar work namely Adaptive Coding for OFDM System [10] and significance of proposed scheme is shown by using simulation results. Significance of proposed scheme is due to the following factors,

1. Adaptive code rate, modulation as well as power
2. More parameters to combat channel hostilities
3. Fuzzy Rule Base System cum GA to choose suitable most combination of code and modulation scheme and power vector based upon a specific Quality of Service and average received channel power to interference noise ratio.

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