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Comparison of Coding Schemes over FRBS Aided AOFDM Systems

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Abstract— **Adaptive techniques are becoming demand of almost every modern communication system. In this technique, transmission parameters are adapted in such a way that the overall throughput of the system is maximized and certain constraints are satisfied. In this paper a similar constrained optimization problem is focused and a fuzzy rule based system (FRBS) is proposed for its solution. The transmission parameters being optimized are practical channel code, modulation symbol and the transmit power. FRBS suggests the optimal code rate and modulation symbol while water-filling algorithm suggests the power vector according to channel conditions at Orthogonal Frequency Division Multiplexing (OFDM) sub-channels, so that throughput can be maximized while bit error rate (BER) and power remain constrained. Comparison of two channel codes namely Product codes and Convolutional code is given while Quadrature Amplitude Modulation (QAM) as Modulation scheme is used under supervision of FRBS. Comparison of both schemes is shown by simulations.**

Keywords-component; OFDM; FRBS; BER; ACMP, Modulation Code Pair, Product Codes, MIDA, Water-filling

I. INTRODUCTION

Adaptive communication is one of the important features of many 3rd Generation (3G) and 4th Generation (4G) systems. In this regard, transmitter optimally selects various transmission parameters like forward error correction code (FECC), modulation size and power etc with respect to the varying channel conditions. If channel conditions are poor then a relatively lower code rate, and smaller modulation symbol and better power can be used. Similarly a comparatively high code rate, a larger modulation symbol and a moderate power can be used. OFDM systems have been used in almost all wireless standards like IEEE802.11 [1] and IEEE802.16 [2] etc. 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 subchannels. The orthognality of subcarriers and addition of a suitable cyclic prefix (CP) makes the system less vulnerable to inter symbol interference (ISI).

In literature many adaptive power and bit loading techniques have been proposed. The idea of adaptive modulation has been proposed in late 90s; however consideration of a practical channel code and other parameters is a 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 2009, Shastri 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].

Atta-ur-Rahman *et al*. proposed a fuzzy rule base system (FRBS) for adaptive coding and modulation in OFDM systems in [11]. In this paper FRBS chooses the best modulation code pair for a given set of channel conditions at different subchannels in OFDM. Product codes were used as FECC and QAM as modulation scheme. In this scheme power distribution was assumed fixed. Scheme was examined and compared with HYPERLAN/2 standard and results shown in terms of simulations.

In [12], same authors examined the role of FRBS for IEEE 802.11n (WIFI) standard. In this paper, Convolutional codes with constrained length 3 were used as forward error correction code and QAM as modulation scheme. Power distribution was considered fixed over all subchannels. The significance of proposed scheme was shown over various schemes of same area like the one proposed by Bockelmann *et al*. in [13]. In which a Bisection method was used for selection of optimum modulation code pair (MCP).

In [14], same authors proposed an FRBS based adaptive coding, modulation and power scheme, in which all three parameters were adapted. FRBS was used for adapting code rate and modulation scheme while Water-filling principle was used for adapting the power vector for all subcarriers at OFDM system. In this paper Product codes were used as FECC and QAM and modulation scheme.

In this paper, we have presented the comparison of two FRBS based adaptive coding and power schemes. In these schemes FRBS is used for adapting modulation and code rate while Water-filling principle is used for adapting the power vector. In one scheme Product codes are used for FECC while in other scheme Convolutional codes was used.

Rest of the paper is organized as follows. System model is given in section 2; section 3 contains a brief introduction of Product 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 and 7 Fuzzy Rule Base System is and water-filling algorithm are explained respectively, 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

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

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 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:

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

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

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 [15]. 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 $[n_1n_2,k_1k_2,d_1d_2]$ and the rate will be R_1R_2. In this way long block codes can be constructed using much shorter constituent block codes. This concept can also be viewed as that product code $\mathbf{\Omega}$ is intersection of two codes $\mathbf{A}_1^{'}$ and $\mathbf{A}_2^{'}$. Where $\mathbf{A}_1^{'}$ is a code represented by all $n_2 \times n_1$ matrices whose each row is a member of code $\mathbf{A}_1$, similarly $\mathbf{A}_2^{'}$ is a code represented by all $n_2 \times n_1$ matrices who's each column is a member of code $\mathbf{A}_2$. This can be written as;

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

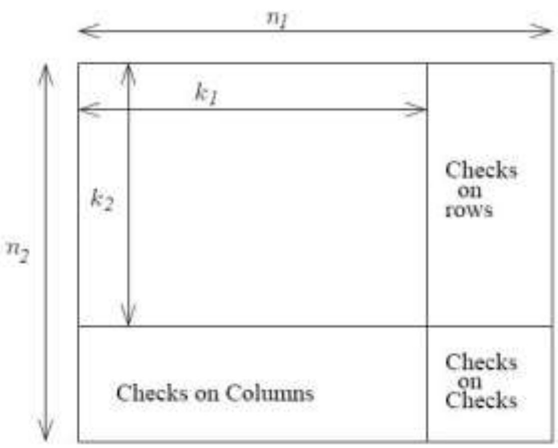

Figure 1. Structure of the Product code

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 [16].

IV. CODED MODULATION

There are two modulation coding schemes investigated. There details is given as follows.

A. First 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

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

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

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

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. 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.

$$P = CxM = \{(c_i, m_j) \mid \forall c_i \in C, \forall m_j \in M\} \quad (8)$$

B. Second Schemes

The codes used in this scheme are non-recursive convolutional codes with code rates taken from the set $C = \{1/4, 1/3, 1/2, 2/3, 3/4\}$ with constraint length 3. For decoding, standard soft output Viterbi decoder is used. For convenience, message bits length is taken equal to the number of subcarriers and standard OFDM interleaver/de-interleaver are used in simulations.

In this scheme the symbols taken from Quadrature Amplitude Modulation (QAM), with rectangular constellation. The modulation symbols are taken from the set $M = \{2,4,8,16,32,64,128\}$.

All of the possible combinations of modulation code pairs in both schemes are plotted using the sequence shown in Fig-2. Few of these graphs are shown in subsequent figures.

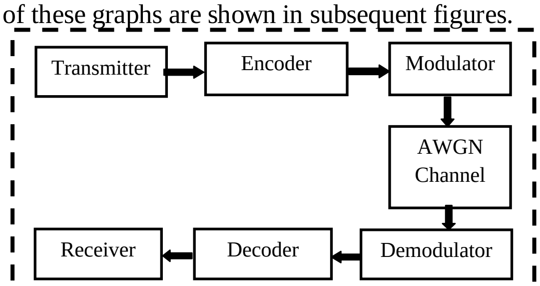

Figure 2. Simulation Model

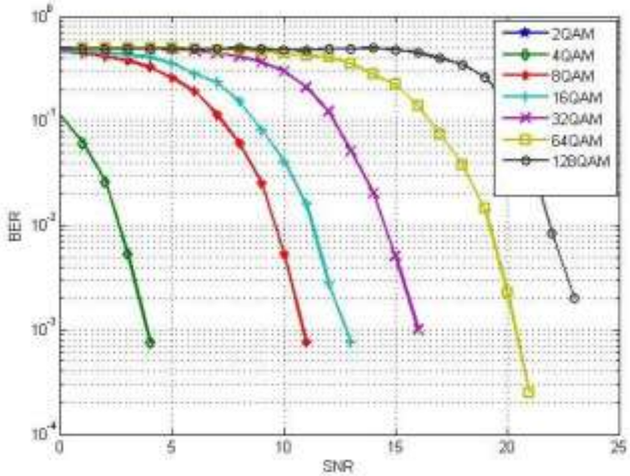

Figure 3: Performance of different QAM schemes using C2 as product code from first scheme

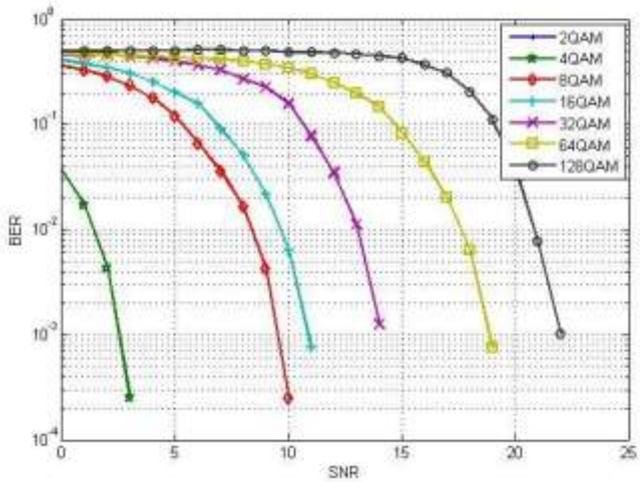

Figure 4: Performance of different QAM schemes using C4 as product code from first scheme

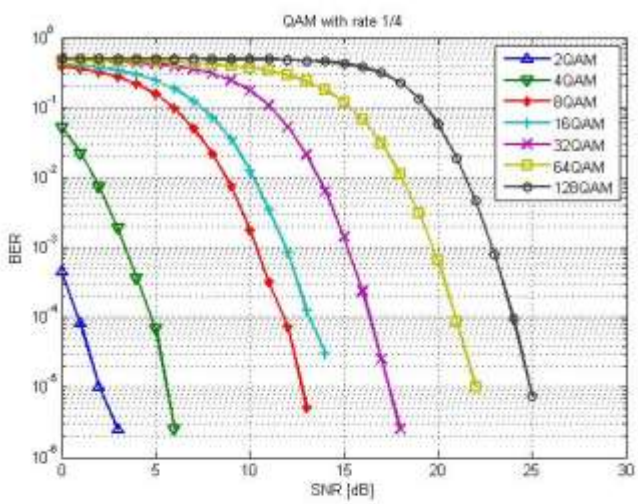

Figure 5. BER comparison of different QAM modulations using rate 1/4 convolutional codes from second scheme

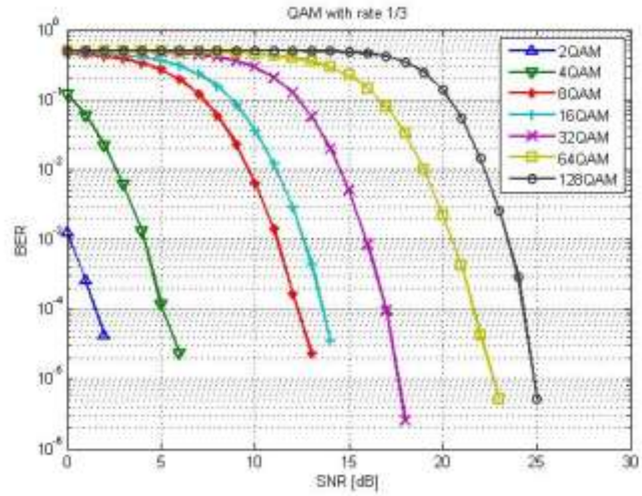

Figure 6. BER comparison of different QAM modulations using rate 1/3 convolutional code from second scheme

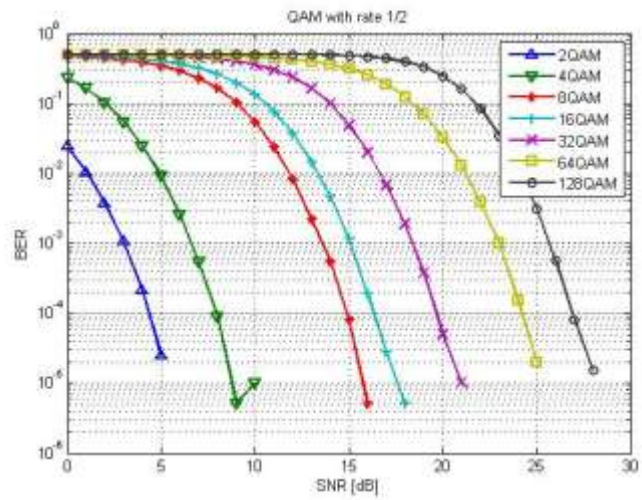

Figure 7. BER comparison of different QAM modulations using rate 1/2 convolutional code from second scheme

V. RATE OPTIMIZATION

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

$$\begin{aligned} &\max \quad R_{Total} = R\log_2(M) \\ &\text{s.t,} \\ &BER_{Total} \le BER_T \qquad (9) \\ &and \\ &P_{Total} = \sum_{i=1}^{N} p_i < P_T \end{aligned}$$

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.

Similarly, in second scheme following cost function is considered.

$$\begin{aligned} &\max \quad R_{Total} = \frac{1}{N}\sum_{n=1}^{N} r_n \\ &\text{s.t,} \\ &BER_n \le BER_{QoS_n} \quad \text{and} \\ &\sum_{n=1}^{N} p_n < P_T \end{aligned} \qquad (10)$$

where $r_n = (\log_2(M))_n R_{C,n}$ is bit rate of nth subcarrier, which is product of code rate and modulation order used, P_T is the available transmit power and BER_{QoS_n} is target BER that depends upon a specific quality of service (QoS) request or application requirement over nth subcarrier, while N is number of subcarriers in OFDM system.

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 interval, based upon the heuristics. Fuzzy logic is recommended for the situations that are vague, ambiguous, noisy or missing certain information. There are many ways to build a Fuzzy Rule Base System, we have used *table lookup scheme* for this purpose. The lookup table is given in fig-8 that is used for creation.

A. Obtaining Graphs

Graphs for different combinations of Codes and Modulation schemes are obtained; few of them are depicted in Fig-3 to 5 according to first scheme and in Fig-6 and 7 according to second scheme.

B. Data Acquisition

Data is obtained from the graphs in terms of input/output (IO) pairs. This is taken by putting the horizontal lines for various bit error rates and then points of intersection of these lines with the curves are noted and stored in a table. This process is shown in Fig-8.

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 then a rule generated for each pair accordingly. This process of rule formulation can be seen in detail in [17].

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 example in first scheme, 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 modulation/demodulation and coding/decoding cost. Similarly, in second scheme, 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.

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. Similarly, if a MCP performs for a good QoS then it can sustain for poor QoS demands. For example in second scheme, let [128,3/4] be 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.

F. 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 ahead.

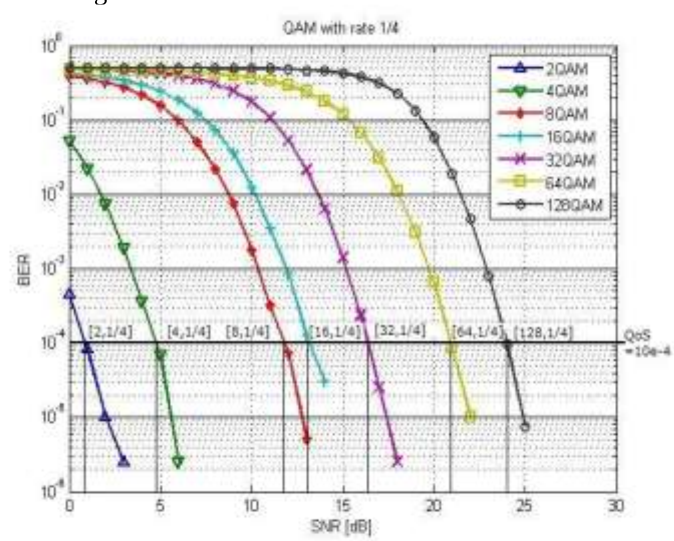

Figure 8. Process of obtaining IO pairs

Components of Fuzzy Rule Base System

A. 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". In first scheme received signal to noise ratio (SNR) is expressed in level 1 to level 9 and Quality of Service (QoS) are given like poor, med, good and high that is $10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ respectively. In second scheme, the received SNR is expressed in level 0 to level 30 and QoS is given in five different levels that are $BER_T = 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}$.

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

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

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 below;

{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 9. Lookup Table for FRBS Creation in first scheme

The lookup table for the first scheme is shown in Fig-9 while for the second scheme it is shown in Fig-10.

SNR-->>																
L0	P2	P2	P2	P2	P2	P2	P2	P1	P1	P1	P1	P1	P1	P1	P1	P1
L1	P3	P3	P2	P2	P2	P2	P2	P2	P2	P2	P1	P1	P1	P1	P1	P1
L2	P4	P3	P3	P2	P2	P2	P2	P2	P2	P2	P2	P2	P1	P1	P1	P1
L3	P7	P7	P7	P7	P7	P7	P7	P2	P2	P2	P2	P2	P1	P1	P1	P1
L4	P7	P7	P7	P7	P7	P7	P5	P5	P5	P5	P3	P3	P1	P1	P1	P1
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	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
								QoS-->>								

Figure 10. Lookup Table for FRBS Creation in second scheme

B. 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.

$$MLBER = -\log(BER)$$
$$BER = 10^{-q} \qquad (11)$$
$$MLBER = -\log(10^{-q}) = q$$

There is one output variable for modulation code pair MCP. In first scheme, there are nine, four and eighteen fuzzy sets used for the input variables SNR, MLBER and output variables MCP, respectively. These are shown in figures

In second scheme there are thirty one, sixteen and twenty-five fuzzy sets are used for the input variables SNR, MLBER and output variables MCP, respectively.

C. Fuzzifier & De-Fuzzifier

Standard triangular fuzzifier is used with AND as MIN and OR as MAX. Standard Center Average Defuzzifier (CAD) is used for defuzzification.

D. Rule Base & Inference Engine

Rule base contains rules against all the IO pairs. In first scheme, there are nine sets (L1 to L9) for first input variable named received SNR and about four sets (low, medium, good and high) for input variable MLBER. Hence there are 36 rules in rule base. This is shown in Fig-11 to Fig-13.

Similarly, in second scheme there are thirty-one sets (L0 to L30) for first input variable named SNR and about sixteen sets (Q1 to Q16) for input variable MLBER. Hence there are 496 rules in rule base. These membership functions are shown in Fig-14 to Fig-16.

Rule base is complete in a sense that rules are defined for all possible combinations of input space. Standard Mamdani Inference Engine (MIE) is used that will infer which input pair will be mapped on to which output point.

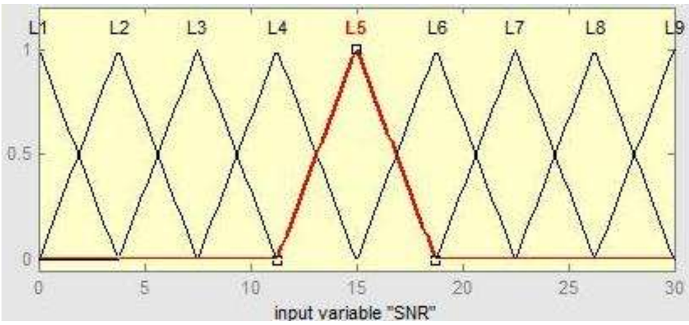

Figure 11. Fuzzy Sets for input variable average received SNR

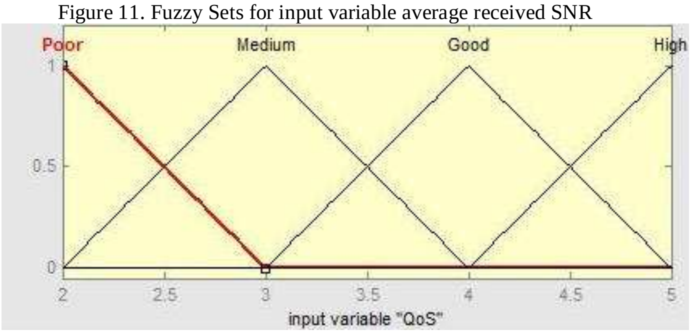

Figure 12. Fuzzy Sets for input variable QoS

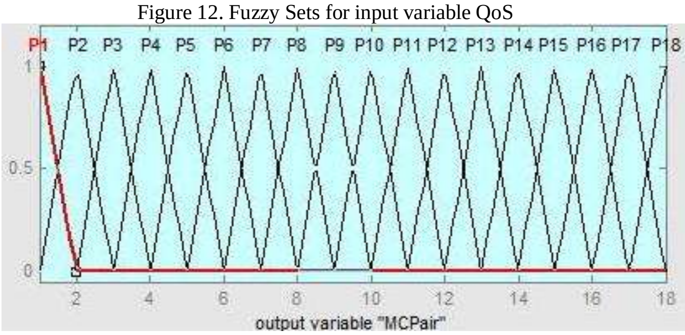

Figure 13. Fuzzy Sets for output variable Modulation Code Pair

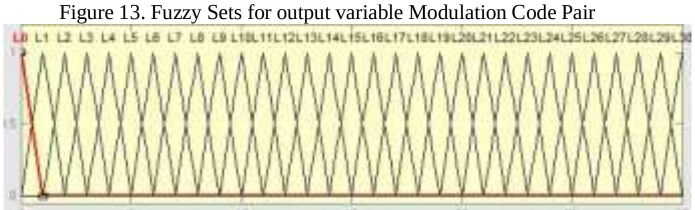

Figure 14. Membership function of first input variable "SNR"

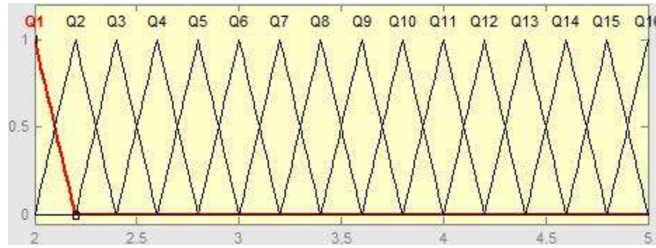

Figure 15. Membership function of second input variable "QoS"

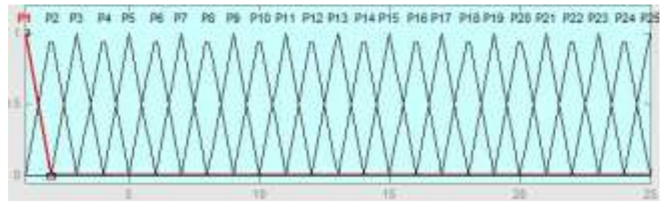

Figure 16. Membership function of output variable "MCP"

Fig-17 and Fig-18 show the rule surfaces for first and second schemes respectively. A rule surface 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.

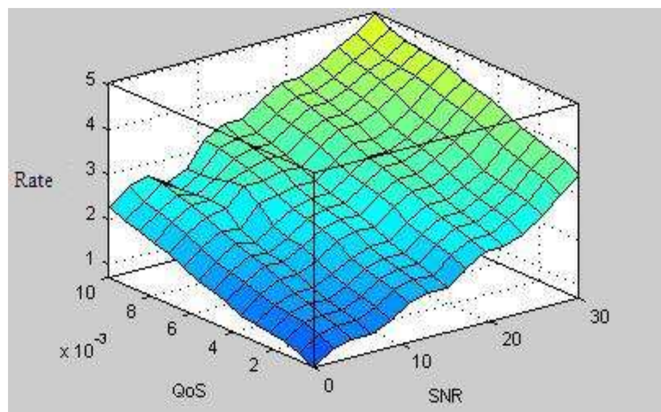

Figure 17. Rule surface for first scheme

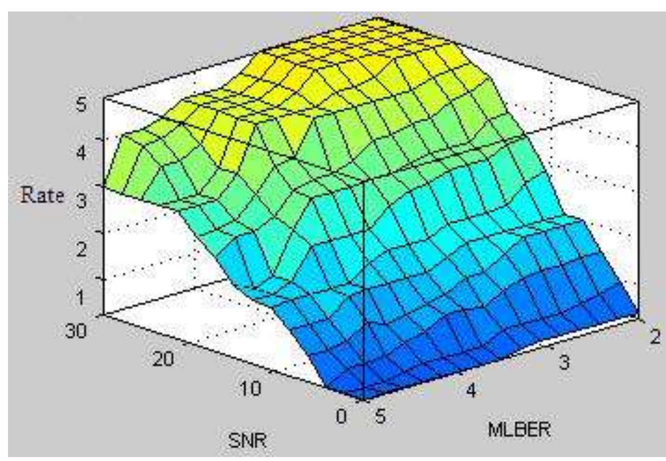

Figure 18. Rule surface for second scheme

VII. The Water-Filling Algorithm

Water-filling principle has been widely 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,

$$p_i + \frac{\sigma_i^2}{|H(f_i)|^2} = K; 1 \le i \le N \qquad (12)$$

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

$$p_i + \frac{1}{(CNR)_i} = K; 1 \le i \le N \qquad (13)$$

Where

$$(CNR)_i = \frac{|H(f_i)|^2}{\sigma_i^2} \qquad (14)$$

the value of the constant K is calculated analytically by [18]

$$K = P_{avg} + \frac{1}{N}\sum_{i=1}^{N}\frac{1}{(CNR)_i} \qquad (15)$$

where P_{avg} is the average transmit power.

VIII. Results

A. First Scheme

In this section both schemes are compared with each other as well as the well-known adaptive techniques. Simulation parameters are enlisted in table2.

In fig-19, first scheme is plotted for various quality of service (QoS) like average BER=10e-1, 10e-2, 10e-3 and 10e-4. 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), for entire OFDM system, then the product of modulation rate and code rate so called modulation-code-product is considered as throughput is plotted, while the power consideration was fixed. In fig-20, adaptive power using water-filling principle is considered. In fig-21, proposed scheme is compared with the Adaptive Coding scheme proposed by Al-Askary in this PhD dissertation [10], in which HYPERLAN/2 standard was focused and adaptation criteria was based upon SNR based thresholds. As simulation results reveal, proposed scheme profoundly performs better than that of proposed by Al-Askary as well as HYPERLAN/2 standard. Also proposed adaptive power outperforms that of the fixed power.

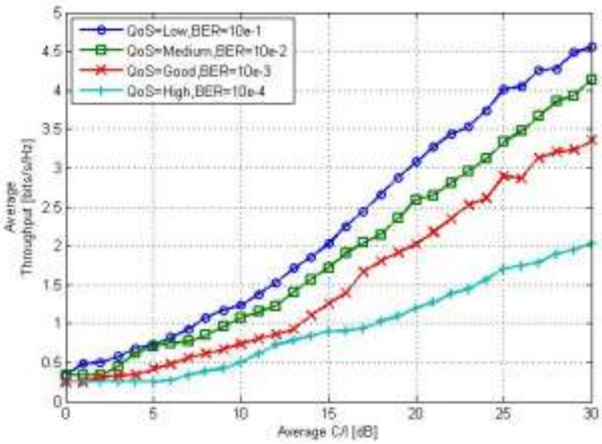

Figure 19. Comparison of proposed scheme for various QoS with fixed power

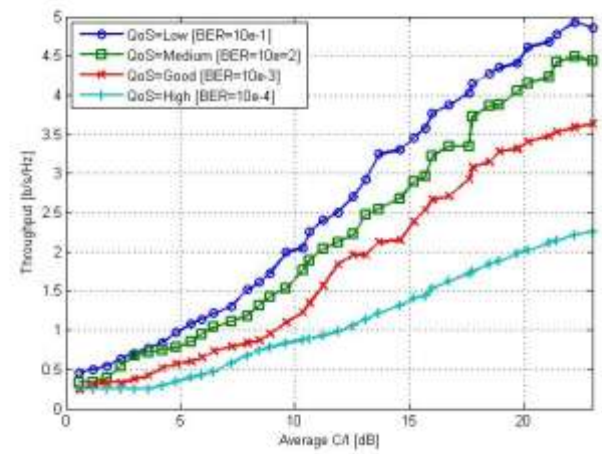

Figure 20. Comparison of proposed scheme for various QoS with adaptive power

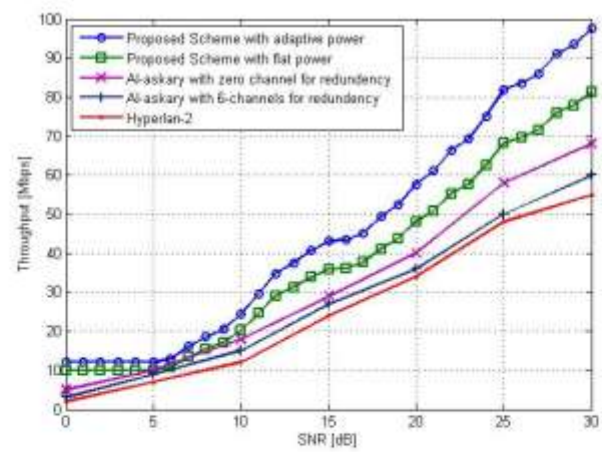

Figure 21. Comparison of proposed scheme with different schemes

B. Second Scheme

In this section we compared both schemes at different quality of service. Fig-22 shows the comparison of both schemes for QoS=10e-2. This graph reveals that second scheme outperforms compare to first scheme as well as fixed power scheme.

Similarly, in Fig-23 and Fig-24 both schemes are compared with each other as well as with adaptive coding and modulation and fixed power case. In all of these graphs it is apparent that second scheme is significantly better than first scheme and fixed power scheme.

The reason that second scheme is better than first is because in first scheme once we choose a modulation code pair using fuzzy rule base system, it remains same for all subcarriers. While in second scheme each subcarrier may have a different modulation code pair after each transmission interval. This difference can be noticed in equ-9 and equ-10.

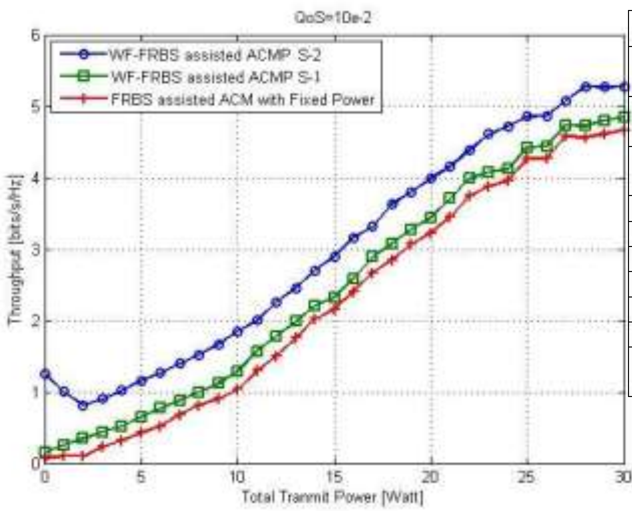

Figure 22. Comparison of both schemes at QoS=10e-2

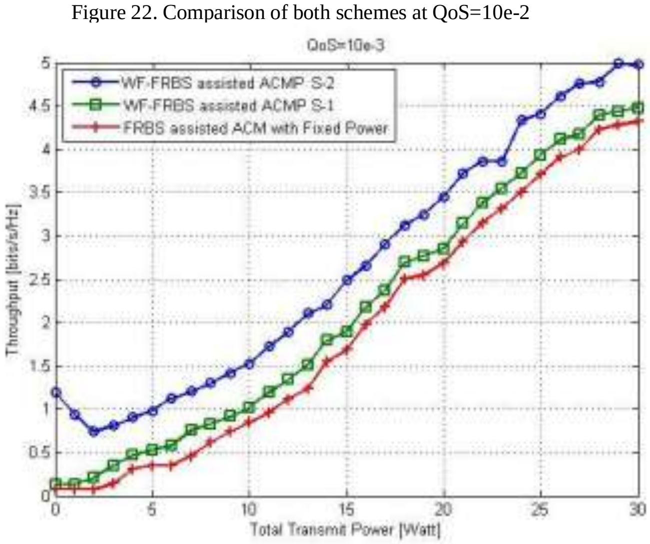

Figure 23. Comparison of both schemes at QoS=10e-3

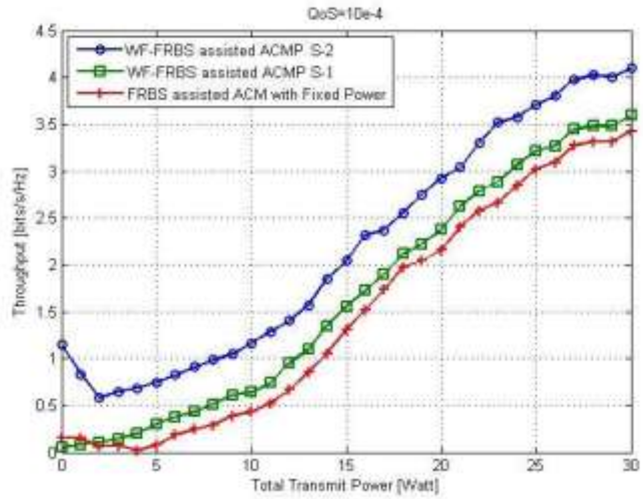

Figure 24. Comparison of both schemes at QoS=10e-4

TABLE II. SIMULATION PARAMETERS

Sr	Parameter name	Value
1	Coding Schemes	Product Codes, Convolutional Codes
2	Code rates in First Scheme	1, 0.9, 0.8, 0.57 (C1 to C4) 0.9,0.81,0.7,0.5 (C5 to C8)
3	Code rates in Second Scheme	0.25, 0.33, 0.5, 0.67, 0.75
4	Modulation Scheme	2, 4, 8, 16, 32, 64, 128 QAM
5	Bits/symbols in modulation	1, 2, 3, 4, 5, 6, 7
6	Total MCPs	8x7=56
7	OFDM Standard used	HYPERLAN/2
8	Number of subchannel	63
9	Adaptation	Modulation, code and power
10	Adaptation Criteria	Fuzzy Rule Base System+Water-filling

IX. CONCLUSIONS

In this paper two adaptive coding, modulation and power schemes are compared. First scheme uses Product codes as FECC while second scheme uses Convolutional codes; remaining all parameters are kept same. This comparison was to show that which coding scheme in contrast to FRBS exhibits better spectral efficiency in an adaptive OFDM (AOFDM) environment. Quadrature Amplitude Modulation is used as modulation scheme while Water-filling principle is used for adapting power in each case. The first scheme was tested for OFDM HYPERLAN/2 standard and compared to a similar work namely Adaptive Coding for OFDM System [10] and comparison of the scheme is shown by simulations.

Second scheme perform better compare to first scheme because in second scheme the decision of modulation code pair is based upon individual channel conditions and each subcarrier may have a different MCP. In first scheme, however, the decision is based on average channel condition and same MCP is used for all subcarriers of OFDM system. Significance of the proposed schemes is due to the following factors,

1. Wide range of Product codes and convolutional codes are investigated. Both coding schemes are being used in practical IEEE standards like HYPERLAN/2 and IEEE802.11n (WIFI)
2. Fuzzy Rule Base System is to choose suitable most combination of code and modulation scheme based upon a specific Quality of Service and average received channel to interference noise ratio (channel state).
3. Water-filling principle in conjunction with FRBS to adapt power vector for all subcarriers.
4. A relatively low complexity decoder (MIDA) of product codes
5. Combined adaptive coding, modulation and power

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