A Design of FIS Based Adaptive OFDM System for Optimized Transmission of Grayscale Images

Anurag Mishra, Kanchan Sharma, and Asok De

Abstract— In this paper, we implement adaptive modulation in OFDM system using Mamdani Fuzzy Inference System (FIS) to transmit grayscale images over AWGN channel. The value of QAM modulation order (M) is decided by using a Mamdani Fuzzy Inference System that meets a maximum predefined target of bit error rate (BER). In the beginning, grayscale image transmission using adaptive M-QAM in OFDM system is carried out successfully. To improve the system performance, we further apply (7, 4) Hamming block codes on image data to be transmitted using same FIS based adaptive OFDM system. The obtained result shows that a significant improvement in terms of high PSNR, BER, SSIM and better spectral efficiency can be achieved using Fuzzy Inference based adaptive modulation scheme used in the present work.

Index Terms— BER, Mamdani Fuzzy Inference System (FIS), OFDM, PSNR, SSIM.

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1 INTRODUCTION

The orthogonal frequency division multiplexing (OFDM) is a transmission scheme in which a single high rate data stream is divided into multiple low rate data streams. These data streams are subsequently modulated using sub-carriers orthogonal to each other. This way the inter symbol interference (ISI) and inter carrier inference (ICI) due to channel dispersion in time induced by multipath delayed spread is considerably reduced. The orthogonality of the modulation technique ensures that the data streams do not interfere with each other. The OFDM optimizes overall channel capacity and improves through put.

The transmission of copyright content in the form of images over AWGN channel using OFDM technique has been successfully demonstrated by Sharma et. al [1].

The objective of the third and fourth generation mobile communication system is to integrate high speed data, video and voice signals. Adaptive OFDM or AOFDM is a potential candidate to accomplish this objective and it is also perceived as a method to increase data capacity, throughput and efficiency. In this kind of system, the transmitter dynamically monitors the channel variations especially in SNR and BER and accordingly adapts to the transmission parameters such as modulation order, coding rate etc.

This is done to maximize efficiency. The throughput monitoring is done in the reverse channel and the adaptation is applied in the forward channel.

The adaptive modulation for OFDM was first proposed by Kalet et. al [2] in 1989. Later Chow et. al [3] and Czylwik et. al [4] revisited and modified this concept in 1995 and 1996 respectively.

However, Sharath B. Reddy et. al [5] discussed the issue of modulation, mode selection on the basis of perceived channel quality. They have argued that as the received signal fades, the modulation level is decreased to a level so as to provide an acceptable bit error rate (BER). They further state that since adaptation in every sub-carrier would be extremely complicated often sub- carriers are grouped together and adaptation is performed on the entire sub-carrier group. This is termed as sub-band adaptive modulation. According to them, the goal of the adaptive modulation is to choose the appropriate mode of transmission in each sub-carrier in order to achieve a good tradeoff between throughput and overall BER. They have taken into account the modulation mode and computed SNR to reversely calculate BER. J. Faezah and K. Sabira [6] have proposed an adaptation procedure by which the channel estimation and mode selection are done at the receiver side and this information is sent to the transmitter using a feedback channel. In their model, adaptation is done frame by frame. They have used a channel estimator to estimate the instantaneous SNR of the received signal. Based on the instantaneous SNR, the best mode is computed for the next transmission frame. This task is done by using a mode selector block. The mode selector and switching between modulator depends upon the instantaneous SNR. Further the switching between modes is done in synchronization with pre-decided switching threshold. Sheshadri K. Sastry [7] has probably for the first time demonstrated the use of Fuzzy Logic interface to simulate the design of adaptive OFDM system. In this paper, he has argued that lower order modulators such as BPSK, 4-QAM and 8-QAM will improve BER but decrease spectral efficiency and speed. On the other hand, employing higher order modulation modes such as 64-QAM, 128-QAM, 256-QAM and 512-QAM improves spectral efficiency and speed at the cost of poor BER. According to him, it is therefore a fit case of optimization by trading off spectral efficiency with BER using fuzzy logic based adaptive OFDM. For this purpose, he has relied upon switching between modulator modes on the basis of instantaneous normalized SNR (E_b/N_o) and existing mode supplied as input to the FIS.

Charu Agarwal et al [8] have successfully used Mamdani fuzzy rule based system to optimize watermark embedding in

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grayscale images. Worldwide Mamdani Fuzzy rule based system is considered superior to other similar systems. Therefore, in the present work, we transmit grayscale images Lena and Baboon over AWGN channel using adaptive QAM technique by involving Mamdani Fuzzy Inference System. For this purpose, we use three input variables namely – Channel E_b/N_o, BER and initial order for this FIS. The output of the FIS is the final modulator mode the adaptive OFDM system has to follow. The membership function used in this work is triangular. We take into account four levels of mode selection for the QAM. These are 4-QAM, 16-QAM, 64-QAM and 256-QAM. The FIS is trained using thirteen fuzzy rules developed by taking into account the given input and output variables. It is concluded that the adaptive OFDM system using FIS performs better than ordinary if-then-else control logic in terms of tradeoff between spectral efficiency and speed on one hand and BER on the other.

2 THEORY AND EXPERIMENTAL WORK

2.1 Orthogonal Frequency Division Multiplexing

The OFDM is a recent technology used in the broadband communication like IEEE 802.11 wireless local area networks (WLANs) and IEEE 802.16 broadband fixed wireless access networks in a wireless multipath environment. The basic principle of OFDM is to split a high rate data stream into a number of lower rate data streams which are transmitted simultaneously over a number of sub- carriers. The dispersion in time caused by multipath delay spread is decreased relatively due to the increase of symbol duration for lower rate parallel sub-carriers. Intersymbol interference (ISI) is completely eliminated by the addition of the guard time in every OFDM symbol [9].

Let $X_m[k]$ denote the m^{th} transmit symbol at the k^{th} subcarrier, m = 0, 1, 2, … ∞ and k = 0, 1, 2, … N-1. Due to serial to parallel conversion, the duration of transmission time for N symbols is extended to NT_s, which forms a single OFDM symbol with a length of T_{sym} (i.e., $T_{sym} = NT_s$). Let $\varnothing_{m,k}$ (t) denote the m^{th} OFDM signal at the k^{th} subcarrier which is given as

$$\varphi_{m,k}(t)=\begin{cases} e^{j2\pi f_k(t-mT_{sym})}, 0<t\le T_{sym} \\ 0, \qquad\qquad \text{elsewhere} \end{cases} \tag{1}$$

Then the passband and baseband OFDM signals in the continuous-time domain can be expressed respectively as

$$x_m(t)=\mathrm{Re}\left\{\frac{1}{T_{sym}}\Phi\sum_{m=0}^{\infty}(t)\left\{\sum_{k=0}^{N-1}X_m[k]\quad_{m,k}\right\}\right\} \tag{2}$$

$$\Rightarrow x_m(t)=\sum_{m=0}^{\infty}\sum_{k=0}^{N-1}X_m[k]e^{j2\pi f_k(t-mT_{sym})} \tag{3}$$

The continuous-time baseband OFDM signal can be sampled at $t = mT_{sym} + nT_s$ with $T_s = T_{sym}/N$ and $f_k = k/T_{sym}$ to yield the corresponding discrete-time OFDM symbol as

$$x_m[n]=\sum_{k=0}^{N-1}X_m[k]e^{j2\pi kn/N} \text{ for } n=0,1,2,....,N-1. \tag{4}$$

which turns out to be the N-point IDFT of QAM data symbols $\{X_m(0), X_m(1),…,X_m(N-1)\}$ which can be computed with less number of complex addition and complex multiplication by using the IFFT.

There are two ways of adding guard interval in OFDM system. One way is to pad zeros as the guard interval. This is known as zero padding (ZP). The second method is that of cyclic prefix (CP) in which the last samples of the OFDM symbol are added as prefix which is only the cyclic extension of the OFDM symbol. Let T_G denotes the length of CP in terms of samples. Then, the extended OFDM symbols have the duration $T_{sym} = T_{sub} + T_G$. The received OFDM symbol ym(t) is expressed by Eqn. 5.

$$y_m(t)=\sum_{k=0}^{N-1}X_m[k]e^{j2\pi f_k(t-mT_{sym})}, mT_{sym}<t\le mT_{sym}+nT_s \tag{5}$$

The transmitted symbol $X_m[k]$ can be reconstructed from $y_m(t)$ by using orthogonality among the subcarriers as

$$y_m[k]=\frac{1}{T_{sym}}\int_{-\infty}^{\infty}y_m(t)e^{-j2\pi kf_k(t-mT_{sym})}dt$$

$$=\frac{1}{T_{sym}}\int_{-\infty}^{\infty}\left\{\sum_{i=0}^{N-1}X_m[i]e^{j2\pi kf_i(t-mT_{sym})}\right\}e^{-j2\pi kf_k(t-mT_{sym})}dt$$

$$=\sum_{i=0}^{N-1}X_m[i]\left\{\frac{1}{T_{sym}}\int_0^{T_{sym}}e^{j2\pi(f_i-f_k)(t-mT_{sym})}dt\right\}=X_m[k] \tag{6}$$

Let $\{y_m(0), y_m(1),……., y_m(N-1)$ be the sample values of the received OFDM symbol $y_m(t)$ at $t=mT_{sym}+ nT_s$. Then, the integration in the modulation process of Eqn (6) can be represented in the discrete time as given by Eqn (7)

$$Y_m[k]=\sum_{n=0}^{N-1}y_m[n]e^{-j2\pi kn/N}=\sum_{n=0}^{N-1}\left\{\frac{1}{N}\sum_{i=0}^{N-1}X_m[i]e^{j2\pi in/N}\right\}e^{-j2\pi kn/N}$$

$$=\frac{1}{N}\sum_{n=0}^{N-1}\sum_{i=0}^{N-1}X_m[i]e^{j2\pi(i-k)n/N}=X_m[k] \tag{7}$$

The equation (7) is a N-point DFT of $\{y_m(0), y_m(1),…, y_m(N-1)$ and can be computed efficiently by using FFT [10].

TABLE 1: OFDM SYSTEM PARAMETERS

FFT/IFFT SIZE	64
No of Data sub-carriers	52
Number of symbols	4000
Cyclic prefix	16
Modulation Scheme used	M-QAM
FEC	(7,4) Hamming linear block error correcting codes
Input data	Grayscale Lena of size 512*512 & Grayscale Baboon of size 512*512.

The OFDM system parameters used in this simulation are mentioned in Table 1.

2.2 Adaptive Modulation

Generally OFDM systems use a fixed modulation scheme. In adaptive modulation scheme, each carrier can have a different modulation type depending on the channel condition. We use 4-QAM, 16-QAM, 64-QAM and 256-QAM modes to transmit gray scale images Lena and Baboon over AWGN channel. Each modulation scheme provides a compromise between the bit error rate and spectral efficiency. If we select the highest modulation scheme within an acceptable BER (1E-03) then the system will have maximum spectral efficiency. The 4-QAM gives poor spectral efficiency of 2 bits/sec/Hz whereas 256-QAM has the best spectral efficiency of 8 bits/sec/Hz. The selection/finalization of the modulation mode/order for each sub-channel is the key parameter of adaptive OFDM/QAM system. If the channel E_b/N_o is low, we prefer a lower level of QAM for the next transmission. On the contrary, if the channel E_b/N_o is high, we prefer higher level of QAM [11]. The design criteria of algorithms used in the selection of modulation scheme for an adaptive system are either BER constraints or constant throughput or both, depending upon the application. As per the channel conditions, various modulation selection algorithms have been proposed recently [12-13], [16-18]. Thus, an adaptive modulation system must require the overhead information to be sent to both transmitter and receiver as both of them should know the modulation scheme being currently in use beforehand. This, in general, is perceived as one of the limitations of the adaptive modulation systems.

2.3 The Mamdani Fuzzy Inference Adaptive System

We propose a Mamdani fuzzy Inference system (FIS) capable of deciding the best modulation order of QAM for the next transmission. This is based on the present values of E_b/N_o and BER. In the present case, three parameters are fed as input to the Fuzzy Inference System (FIS) as available in the Fuzzy toolbox of Matlab software. Fig. 1 shows the block diagram of this FIS.

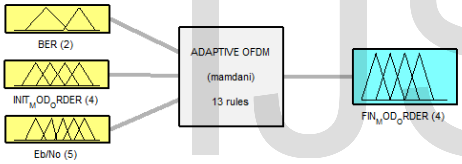

Fig. 1: Block diagram of Fuzzy Inference System

(1) Fuzzy Input Variables

a) Log bit error rate (LBER) represents Quality of Service (QoS) and is divided into two levels as per the inference rules defined in this work. This variation is compiled in Table 2.

TABLE 2: VARIATION OF BER AND LBER

LEVELS	BER	$\log_{10}$(BER)
Medium (M)	1E-06<BER<1E-03	$-6<\log_{10}(BER)<-3$
High (H)	BER>1E-03	$\log_{10}(BER)>-3$

Note from Table 2 that the selected values of BER of a required QoS ranges from 1E-01…1E-06 while it is required that the range of the fuzzy variable should be equally spaced and clearly quantifiable. In other words, the FIS should be able to give a crisp output value. It is observed that for very small values of BER as mentioned above, the FIS generates garbage. Therefore, to achieve crisp outputs, the operation LBER = $\log_{10}$(BER) instead of BER is carried out for computation. Fig. 2 depicts the fuzzified values of BER used in this experiment.

b) Initial Modulation Order (init_mod_order) represents the existing modulation order and is divided into four levels ranging from 4-QAM to 256-QAM as per the inference rules used in this work. Fig. 3 shows the fuzzy variation of initial modulation order used in this work.

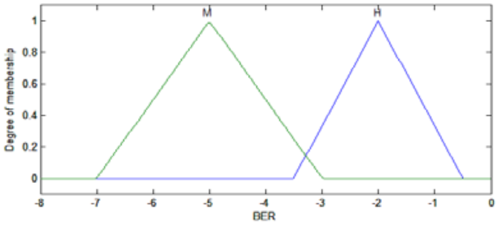

Fig. 2: Fuzzy variation of BER

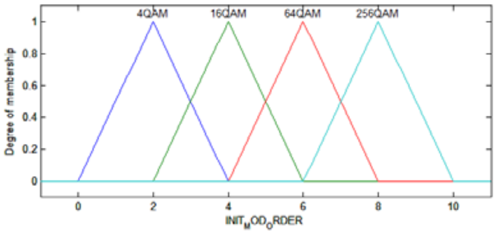

Fig. 3: Fuzzy variation of initial modulation order

c) Normalized Signal to Noise Ratio (E_b/N_o) represents the AWGN channel E_b/N_o and is divided into five levels as per the inference rules used in this work. The E_b/N_o variation for image transmission without using (7, 4) Hamming linear block error correcting code is compiled in Table 3(a). On the other hand, Table 3(b) compiles its variation for image transmission by taking into account (7, 4) Hamming linear block error correcting code.

TABLE 3 (A) VARIATION OF CHANNEL E_B/N_O (WITHOUT (7, 4) HAMMING ERROR CORRECTING CODE

	Range
VERY LOW	$4< E_b/N_o <12$
LOW	$10< E_b/N_o <16$
MEDIUM	$15< E_b/N_o <21$
HIGH	$18< E_b/N_o <26$
VERY HIGH	$E_b/N_o >22$

TABLE 3 (B) VARIATION OF CHANNEL E_B/N_O (WITH (7, 4) HAMMING ERROR CORRECTING CODE)

	Range
VERY LOW	$4< E_b/N_o <10$
LOW	$8< E_b/N_o <16$
MEDIUM	$14< E_b/N_o <20$
HIGH	$18< E_b/N_o <26$
VERY HIGH	$E_b/N_o >22$

Fig. 4 shows the fuzzy variation of channel E_b/N_o used in this work.

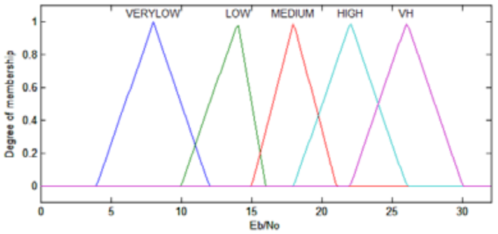

Fig. 4: Fuzzy variation of channel E_b/N_o

(2) Fuzzy Output Variables

The Mamdani Fuzzy Rule Based Inference System used in this work produces a single output known as final modulation order (fin_mod_order). Fig. 5 shows the fuzzy variation of this output parameter. It is also classified into four different levels ranging from 4-QAM to 256-QAM.

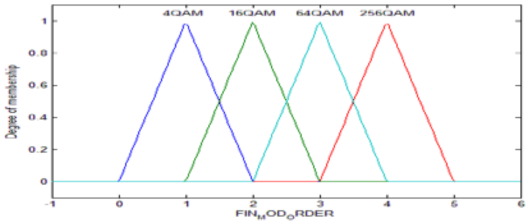

Fig. 5: Fuzzy variation of final modulation order

(3) Fuzzy Inference Rules

The Fuzzy Inference System (FIS) used in this work is configured by developing thirteen fuzzy rules mentioned in Listing 1. This design of the FRBS is carried out in MATLAB 7.8 Fuzzy System Toolbox.

Listing 1: Thirteen fuzzy rules

1. If (ber is high) and (E_b/N_o is verylow) then (fin_mod_order is 4qam)
2. If (ber is high) and (E_b/N_o is low) then (fin_mod_order is 16qam)
3. If (ber is high) and (E_b/N_o is medium) then (fin_mod_order is 64qam)
4. If (ber is high) and (E_b/N_o is very high) then (fin_mod_order is 256qam)
5. If (ber is medium) and (init_mod_order is 4qam) and (E_b/N_o is very low) then (fin_mod_order is 4qam)
6. If (ber is medium) and (init_mod_order is 4qam) and (E_b/N_o is low) then (fin_mod_order is 16qam)
7. If (ber is medium) and (init_mod_order is 16qam) and (E_b/N_o is low) then (fin_mod_order is 16qam)
8. If (ber is medium) and (init_mod_order is 16qam) and (E_b/N_o is medium) then (fin_mod_order is 64qam)
9. If (ber is medium) and (init_mod_order is 64qam) and (E_b/N_o is medium) then (fin_mod_order is 64qam)
10. If (ber is medium) and (init_mod_order is 64qam) and (E_b/N_o is high) then (fin_mod_order is 256qam)
11. If (ber is medium) and (init_mod_order is 256qam) and (E_b/N_o is very high) then (fin_mod_order is 256qam)
12. If (ber is high) and (E_b/N_o is high) then (fin_mod_order is 256qam)
13. If (ber is medium) and (init_mod_order is 256qam) and (E_b/N_o is high) then (fin_mod_order is 256qam)

3 RESULTS & DISCUSSION

3.1 Transmission of Grayscale Images without Error Correcting Code:

In the first part of this work, grayscale Lena and Baboon images are transmitted over a AWGN channel using adaptive OFDM modulation scheme both with and without using Mamdani type FIS. These images are received at the receiver and examined for their visual quality by using two different image quality assessment metrics-peak signal to noise ratio (PSNR) and structural similarity index (SSIM). PSNR is a metric which compares the luminance value of respective pixel coefficients of test and reference images and amplifies the difference between the two. The difference is computed and used as an assessment of image quality. The PSNR is not perceived as a metric which behaves according to human visual system [19]. Therefore, another metric commonly known as SSIM and is based on structural vector components of the image is also used. In this manner, the visual quality of the received image is also taken into account. This is done to investigate the image transmission in a more meaningful manner. The PSNR and SSIM are given by Eqn. 8 and Eqn. 9 respectively.

$$\mathrm{PSNR}(I,\bar{I})=10\times\log_{10}\frac{255^2}{\mathrm{MSE}(I,\bar{I})}(\mathrm{dB}), \tag{8}$$

$$\mathrm{SSIM}(I,\bar{I})=\frac{(2\mu_I\mu_{\bar{I}}+c_1)(2\sigma_{I\bar{I}}+c_2)}{(\mu_I^2+\mu_{\bar{I}}^2+c_1)(\sigma_I^2+\sigma_{\bar{I}}^2+c_2)} \tag{9}$$

Where $\mathbf{I}$ is the grayscale value of the original image, $\bar{I}$ is the reconstructed grayscale image at the receiver, μ_I is the average of I, $\mu_{\bar{I}}$ is the average of $\bar{I}$, σ_I^2 is the variance of I, $\sigma_{\bar{I}}^2$ is the variance of $\bar{I}$, $\sigma_{I\bar{I}}$ is the covariance of I and $\bar{I}$, $c_1=(k_1L)^2$, $c_2=(k_2L)^2$, L is the dynamic range of pixel values, $k_1=0.01$ and $k_2=0.03$. These parameters are optimized by Zhou Wang & Alan Conrad Bovik [20].

Fig. 6(a): Original grayscale image Lena

PSNR = 40.8338 SSIM=0.9879

Fig. 6(b): Received grayscale image Lena at E_b/N_o=12

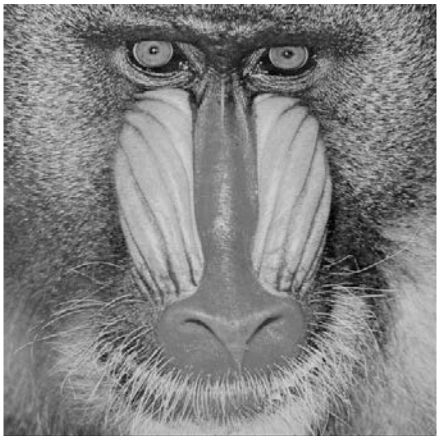

Fig. 7(a): Original grayscale image Baboon

PSNR = 42.5151 SSIM= 0.9961

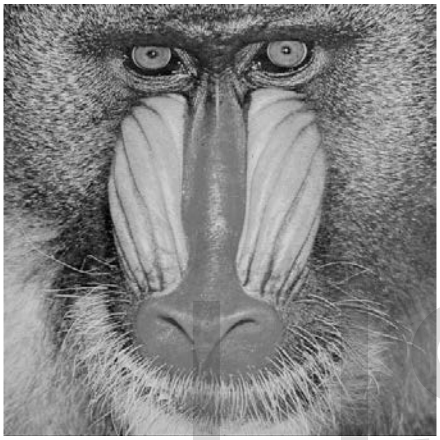

Fig. 7(b): Received grayscale image Baboon at E_b/N_o=12

Figs. 6(a) and 7(a) shows the original grayscale Lena and Baboon image respectively. Figs. 6(b) and 7(b) shows the received Lena and Baboon images at E_b/N_o =13. Moreover, at the receiver side, we also calculate BER of the received image w.r.t transmitted image. The role of the fuzzy logic controller by observing the values of BER, init_mod_order and Channel E_b/N_o is to give a crisp output indicating the modulation order of QAM for the next transmission. The same information is conveyed to both the transmitter and the receiver for the next transmission. We compute the values of BER, QAM order for the subsequent transmission PSNR and SSIM for transmitted images with respect to Channel E_b/N_o. Figs. 8-10 respectively depict the plots of BER, PSNR and SSIM with respect to E_b/N_o both without and with using Mamdani type Fuzzy Inference System (FIS) for transmitted grayscale Lena image. The computed values are represented in the same plot depicting with or without using FIS to give a comparative idea between them. Thereafter, we transmit Baboon grayscale image over AWGN channel using same adaptive OFDM scheme with and without Mamdani type FIS. In this case, the values of the same parameters are computed w.r.t Channel E_b/N_o. These parameters are plotted and are shown in Figs. 11-13 respectively.

A careful observation of these results leads us to the following interpretation:

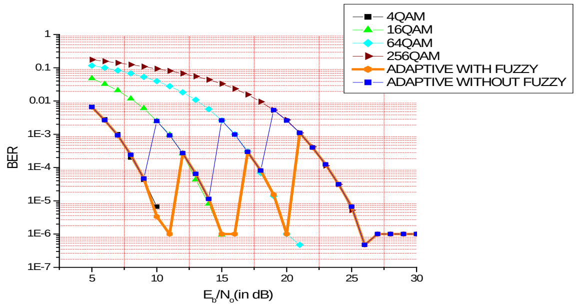

Fig. 8: Plot of BER w.r.t. Channel E_b/N_o for transmitted Lena image

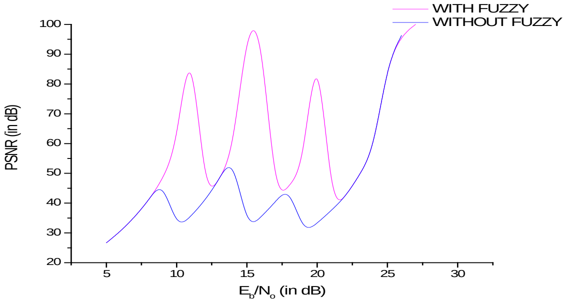

Fig. 9: Plot of PSNR w.r.t. Channel E_b/N_o for the transmitted Lena image

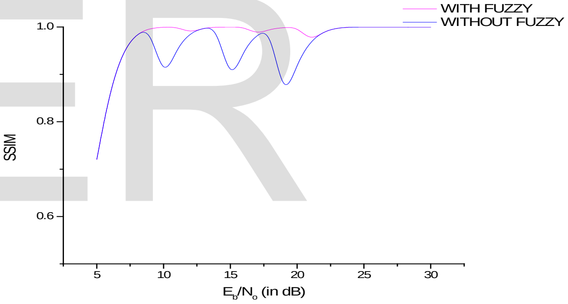

Fig. 10: Plot of SSIM w.r.t. Channel E_b/N_o for transmitted Lena image

1. In this paper, the mode selection for QAM order is done by using Mamdani Fuzzy Inference System (FIS) in case of transmission of grayscale images over AWGN channel. We have successfully demonstrated the potential of optimizing transmission of grayscale images over AWGN channel using fuzzy logic. Although, in principle, the FIS itself is a non adaptive intelligent system, yet a good degree of adaptation to select the order of the modulation scheme is introduced in the procedure used in this work.

This is done by switching the modulation order from 4-16, 16-64 and 64-256 or vice versa in the present work. It will be an interesting avenue to investigate the level of adaptability of the intelligent system by making it hybrid with either a BPN or an RBF neural network.

2. The FIS used in this work is trained by using three input parameters – Channel E_b/N_o, BER and the initial QAM order to obtain a crisp output value which is rounded off to be referred to as the final QAM order. All other experiments which used a similar or a different kind of FIS to transmit digital content in any form using QAM technique use channel E_b/N_o and initial QAM order only as its inputs [7].

3. As a matter of comparison, the PSNR of non-adaptive or fixed transmission scheme is low and SSIM of non-adaptive scheme saturates at high Channel E_b/N_o [1]. This is because the low constellation size limits the maximum source data that can be transmitted. On the contrary, for an adaptive modulation system, the amount of transmitted data varies in accordance with the channel parameters and this leads to achieving a high PSNR and SSIM after reception.

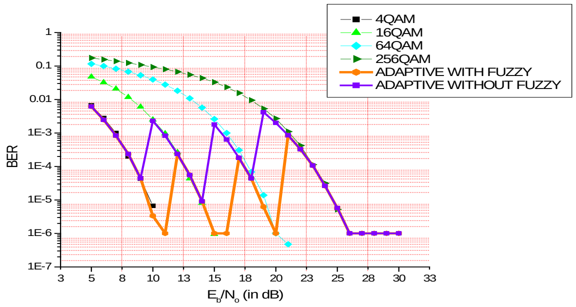

Fig. 11: Plot of BER w.r.t. Channel E_b/N_o for transmitted Baboon

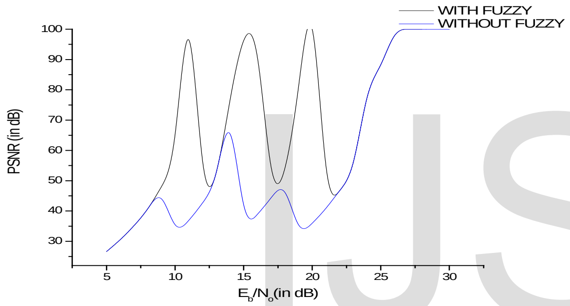

Fig. 12: Plot of PSNR w.r.t. Channel E_b/N_o for transmitted Baboon

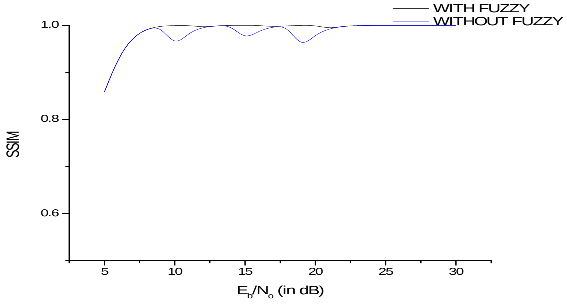

Fig. 13: Plot of SSIM w.r.t. Channel E_b/N_o for transmitted Baboon image

4. In an adaptive scheme when channel conditions are bad, the quality of transmission can be improved upon by transmitting the data at a much lower rate i.e., adapting for a lower modulation order. On the other hand, if Channel E_b/N_o and BER are conducive to transmission, higher modulation order can be selected. This kind of switching is not possible in a non-adaptive transmission system. Even though, if we try to implement an adaptive system by using a simple if-then-else logic, it does not represent a real life situation. This is clearly evident by the results presented in the plots of Figs. 8-10 and Figs. 11-13 respectively for Lena and Baboon. Thus, to optimize the transmission of the grayscale images over AWGN channel using adaptive QAM modulation scheme, the FIS is the best option available to us.

3.2 Transmission of Grayscale Images by Applying (7, 4) Hamming Linear Block Error Correcting Code

As mentioned in Section II, we transmit grayscale images:- Lena and Baboon in the same manner described above by using (7, 4) Hamming linear block error correcting code. All previous parameters are computed for grayscale Lena and Baboon images.

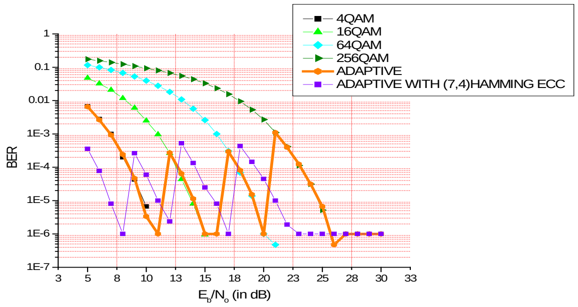

Fig. 14: Plot of BER w.r.t channel E_b/N_o for transmitted Lena using (7, 4) Hamming error correcting code

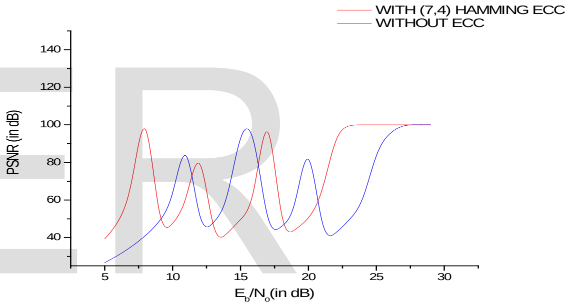

Fig. 15: Plot of PSNR w.r.t Channel E_b/N_o for transmitted Lena image using (7, 4) Hamming error correcting code

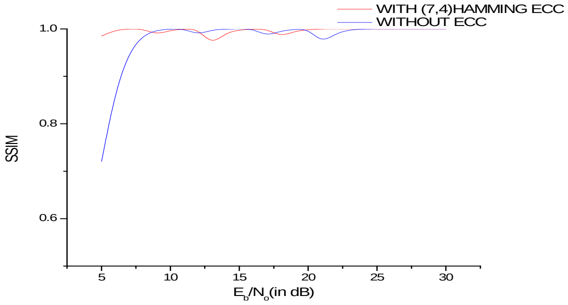

Fig. 16: Plot of SSIM w.r.t Channel E_b/N_o for transmitted Lena image using (7, 4) Hamming error correcting code

The corresponding plots are depicted in Figs. 14-16 respectively for grayscale Lena image. For grayscale Lena transmitted in this manner, a comparative plot of BER w.r.t Channel E_b/N_o with and without using error correcting code is shown in Fig. 14. Similar plot for PSNR and SSIM w.r.t Channel E_b/N_o with and without ECC are respectively shown in Figs. 15-16. In the first part of this work, it is clearly established that FIS produces better results in comparison to ordinary if-then-else logic. Therefore, in the second part of this work only FIS based adaptive OFDM modulation is implemented. However, a comparison of the results is made on the basis of implementing the transmission with or without ECC.

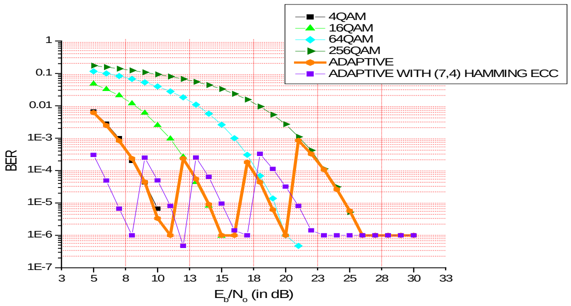

Fig. 17: Plot of BER w.r.t Channel E_b/N_o for transmitted grayscale Baboon using (7, 4) Hamming error correcting code

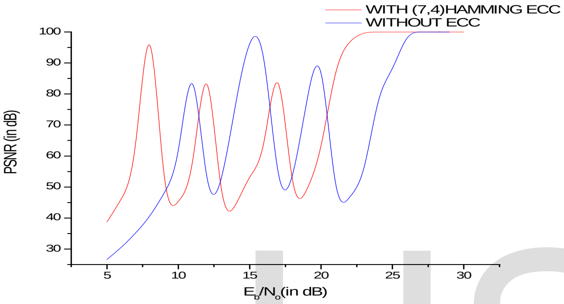

Fig. 18: Plot of PSNR w.r.t channel E_b/N_o for transmitted Baboon using (7, 4) Hamming error correcting code

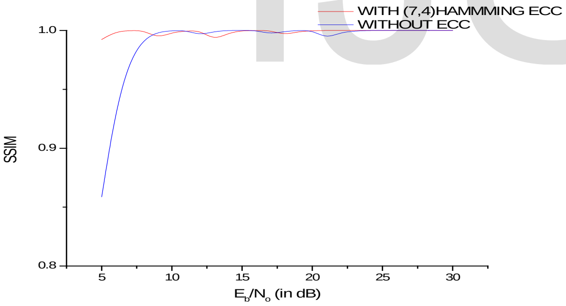

Fig. 19: Plot of SSIM w.r.t channel E_b/N_o for transmitted Baboon using (7, 4) Hamming error correcting code

Figs. 17-19 depict similar plots obtained by transmitting Baboon grayscale image.

A close observation of these results leads us to following interpretation:

1. These results clearly depict a similar adaptive behavior in terms of mode selection for the QAM scheme to be chosen next. Fig. 14 and Fig. 17 indicate that the mode selection is executed in the same manner as without error correcting code. However, with error correcting code, the switching does take place at a lower Channel E_b/N_o in comparison to that without ECC. A similar result is presented by Sharma et. al [1] wherein it is clearly indicated that with the application of error correcting code, the transmission of grayscale images can be accomplished at a much lower value of Channel E_b/N_o.
2. There is a resemblance in the variation of PSNR w.r.t Channel E_b/N_o as per Fig. 15 for grayscale Lena and Fig. 18 for grayscale Baboon transmitted with the error correcting code. It can be easily noted that PSNR gets saturated at lower Channel E_b/N_o values. A similar result is also presented by Sharma et. al [1] wherein it is shown that PSNR does get saturated at a much lower Channel E_b/N_o value. However, we found that PSNR follows a stable path in [2] unlike in this case. The instability in PSNR plot is attributed to adaptable switching between QAM orders optimized by the used FIS while it gets saturated at lower channel E_b/N_o with the application of error correcting code.
3. An identical behavior is depicted for SSIM plots w.r.t Channel SNR both for grayscale Lena and grayscale Baboon transmitted with error correcting codes. The plot of this quantity is also found to be unstable like PSNR and they do get saturated at lower Channel E_b/N_o with an application of error correcting codes. (Figs. 16 & 19 respectively for Lena and Baboon)

It should be noted that the notion of adaptability introduced in the present work does not have any relationship with the application of fuzzy logic with or without application of error correcting code. This is because the Fuzzy Inference System (FIS) as an intelligent system lacks in adaptability which can be successfully supplemented by integrating it with an Artificial Neural Network (ANN) or combining it (FIS) with an evolutionary algorithm such as genetic algorithm (GA). The issue of adaptability discussed in this paper or in other references mentioned in Section I is limited to the switching for mode selection of the QAM scheme. The fuzzy inference system is used to optimize the process of switching which is an important aim/objective of this work.

4. CONCLUSIONS

In view of this discussion, we conclude that optimized transmission of grayscale Lena and Baboon images over AWGN channel using adaptable mode selection of the QAM scheme is successfully accomplished by means of Mamdani type Fuzzy Inference System (FIS). The results are further improved upon by applying (7, 4) Hamming linear block error correcting code while transmitting the grayscale images over the said channel. It shall, however, be an interesting avenue to examine and analyze the integration of Artificial Neural Networks (ANNs) with the fuzzy logic employed in this case so that the necessary adaptability which an FIS lacks otherwise can be successfully compensated.

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