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Neuro-Fuzzy Based Adaptive Coding and Modulation for Performance Improvement in OFDM Wireless Systems

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Abstract

In a scarce radio spectrum, the future wireless technologies are supposed to deliver high data rate information with error free communication. Adaptive coding and modulation (ACM) scheme with OFDM systems allow the efficient use of available bandwidth to maximize spectral efficiency and reduce BER. Due to its complexity and the uncertainty of the wireless channel, the conventional non-soft computing methods such as adaptive techniques do not react to the changing environment. Fuzzy logic based ACM is good in decision-making in uncertain environment and performs better than adaptive and non-adaptive techniques but cannot learn from training examples. Due to its learning capability, neural networks show superiority to the fuzzy logic system. The neuro-fuzzy logic combines the merits of both neural system and fuzzy logic. In this paper, a neuro-fuzzy based adaptive coding and modulation for OFDM wireless system is proposed and simulated in MATLAB. The simulation results show that, the proposed scheme gives significantly better performance in terms of spectral efficiency and bit error rate than the existing fuzzy logic based ACM, adaptive and non-adaptive techniques.

Keywords: Adaptive Coding and Modulation; BER; Neuro-Fuzzy Logic; OFDM; SNR; Spectral efficiency; Wireless systems

INTRODUCTION

The emerging new electronic devices require improved wireless technologies to process information at a higher data rates with good quality of service (QoS). Spectrally efficient data transmission methods are becoming more common requirement for wireless communication that share the scarce spectrum to increase its performance. Adaptive coding and modulation (ACM), is a key technology that adapts code rate and modulation order depending on the time-varying wireless channel conditions to maximize throughput/spectral efficiency and reduce bit error rate (BER) [1].

In ACM techniques, selection of desired coding rate and modulation order depends on the estimated SNR and calculated BER. When the estimated signal-to-noise ratio (SNR) is high, higher modulation order with higher coding rate can be used to increase spectral efficiency [2, 3]. In other words, if the BER is low and SNR is high, higher coding rate and modulation order such as 3/4 and 256QAM can be employed. On the other hand, during worst channel condition, lower coding rate and modulation order like BPSK and 1/4 code rate is used to maintain link availability.

In Orthogonal Frequency Division Multiplexing (OFDM) technique, a signal with high capacity is divided into many low capacity streams and then each stream is modulated with different orthogonal subcarriers. The OFDM system effectively uses the allocated spectrum and combat to Intersymbol Interference (ISI) resulting in errors [4]. OFDM is being employed in several wireless technology standards such as LTE, IEEE 802.11n (WiFi) and IEEE 802.16 (WiMAX) to provide high data rate [5]. Depending on quality of the wireless channel, each subcarrier can be encoded and modulated with different coding rate and modulation order to maximize the throughput. Hence, selection of the desired coding and modulation order is an important concern to have an enhanced system performance for OFDM systems.

An adaptive modulation for OFDM system is proposed in [6, 7, 8]. The adaptive modulation outperforms compared to non-adaptive techniques. A SNR based switching threshold range for different QAM under AWGN channel is proposed by [9] for OFDM system. In these investigations, the constellation size is varied to improve performance of the wireless system. For adaptive coding and modulation proposed by [10, 11, 12], the transmitter selects an appropriate constellation size and coding rate based on the measured SNR to maintain constant BER. A significant improvement is shown on data rate and reduction in BER over the fixed transmission techniques. In [1] by employing various coding rate and modulation can enhance the spectral efficiency with target BER.

A fuzzy logic system based adaptive modulation for OFDM system is proposed in [13, 14, 15] to maximize the data rate and reduce BER. An adaptive modulation based non-data aided SNR estimation [16] and a modified adaptive modulation for performance improvement [17] for OFDM systems are proposed using fuzzy logic. Fuzzy systems target in decreasing the BER even in condition when signal-to-noise ratio increases [18]. The results showed that the fuzzy logic based adaptive modulation performs better than non-adaptive modulation techniques. Moreover, an adaptive coding and modulation using fuzzy logic approach in OFDM system is proposed by [19]. An intelligent link adaption technique [20] and adaptive resource allocation using fuzzy and product codes for OFDM systems has been proposed in [21]. Both coding rate and modulation order are allowed to vary and the decision is made using fuzzy logic. A significant improvement is shown using soft-computing intelligent systems compared to the adaptive and non-adaptive coding and modulation schemes.

In this paper, a neuro-fuzzy based adaptive coding and modulation for performance enhancement in OFDM wireless systems is proposed and a comparison is done to other well-known models such as fuzzy based ACM and adaptive techniques using MATLAB to show superiority of neuro-fuzzy logic system. This paper consists of proposed model, review and modelling of the neuro-fuzzy logic, performance comparison of the proposed model to other techniques and lastly conclusion is presented.

PROPOSED MODEL

In this section, a neuro-fuzzy controller is used in adaptive coding and modulation to improve the performance of wireless communication systems. The proposed system block diagram is shown in figure 1 and MATLAB environment is used for simulation purpose. A digital data source is encoded using a convolutional encoder with different coding rate and then it is modulated by different modulation techniques namely Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM). The encoded and modulated symbols are fed to the OFDM transmitter. After applying the Inverse Fast Fourier Transform (IFFT), the time domain OFDM signal can be expressed as:

$$s(n) = \sum_{k=0}^{N-1} S(k) e^{j2\pi nk/N}, \; 0 \le n \le N-1 \qquad (1)$$

where, $S(k)$ is the coded symbol at the k_{th} subcarrier, $s(n)$ is the time domain sample and N is number of subcarriers for OFDM symbols.

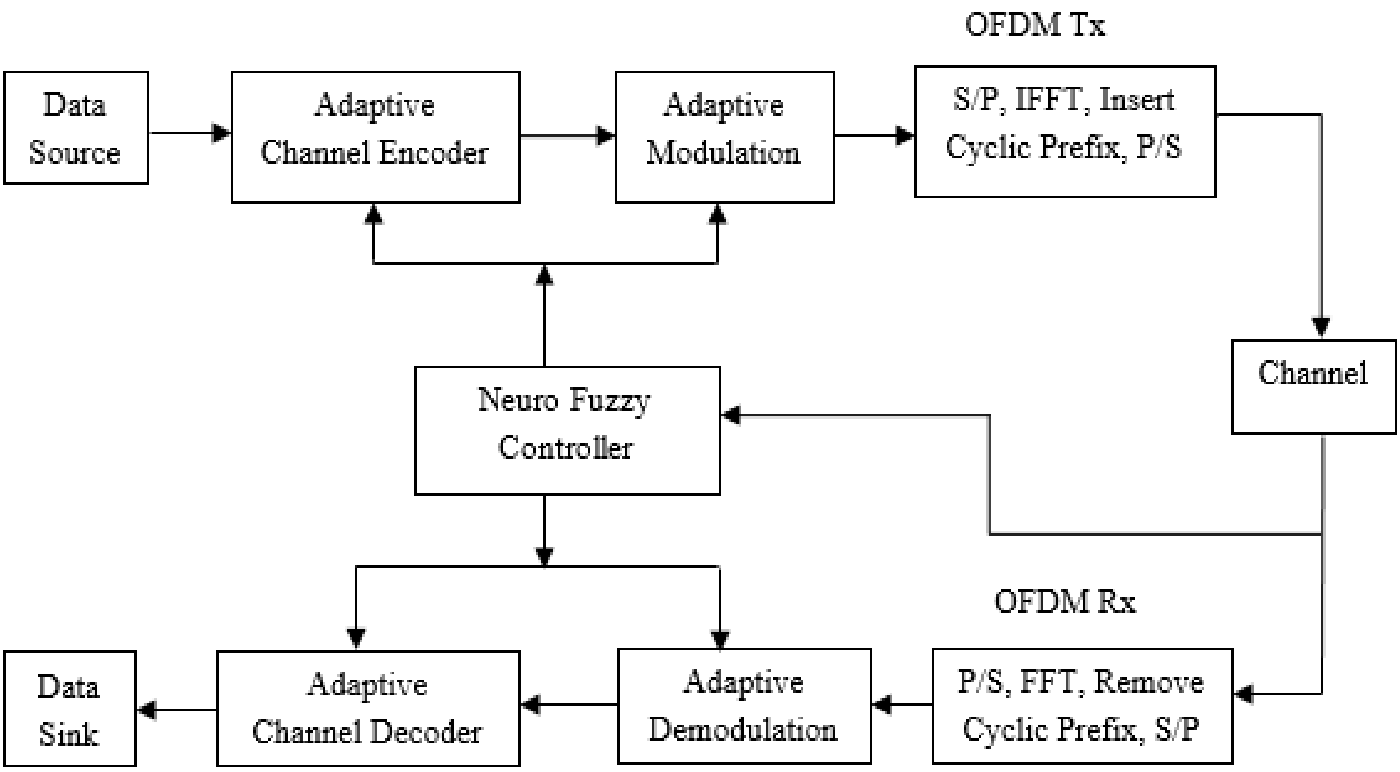

Figure 1: Proposed block diagram

To avoid the intersymbol interference, cyclic prefix is appended at the transmitter section of the OFDM signal [22]. AWGN is then added to the OFDM signal before transmission. The frequency domain of received symbol after the FFT is given by:

$$Y(k) = H(k)S(k) + e(k)\,,\ 0 \le k \le N-1 \qquad (2)$$

where, *Y(k)* is the received OFDM symbol, *H(k)* is the frequency response of the channel and *e(k)* is the channel noise.

Assuming the same modulation order and coding rate for all subcarriers within the OFDM block, maximization of spectral efficiency (η) in adaptive coding and modulation with fixed transmit power is given by:

$$max\ \eta = R_c \log_2(M) \text{ such that } \overline{BER}(\bar{\gamma}) \le BER_T \qquad (3)$$

where, $\bar{\gamma}$ is the average SNR, R_c *is the* code rate, $\overline{BER}$ is the average BER, BER_T is the target BER and M is the modulation order.

The bit error rate is calculated for each SNR by varying the modulation order and coding rate in OFDM wireless systems based on the system parameters shown in table 1.

Table 1: System parameters

Schemes	Parameter values
SNR	0-35dB
BER	10^{-6} to 0.01 bits/sec/Hz
Modulation scheme	BPSK, QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM
FFT size	256
Cyclic prefix	1/4
Convolutional coding rate	1/4, 1/3, 1/2, 2/3, and 3/4
Spectral efficiency or data rate	0.25 to 6.75bits/sec/Hz
Channel model	AWGN

The given SNR, BER, coding rate and modulation order that reveal the nature of the wireless channel are used as inputs to the neuro-fuzzy controller to determine the desired modulation order and code rate to maximize the data rate by maintaining the target BER.

NEURO-FUZZY LOGIC FOR PERFORMANCE IMPROVEMENT IN OFDM SYSTEMS

In fixed coding and modulation scheme, the OFDM uses only single coding rate and modulation order to improve either the spectral efficiency or BER. For an adaptive coding and modulation technique, the coding rate and modulation order are varied dynamically to behave on the time-varying channel thus both capacity and BER are enhanced compared to fixed schemes. Due to complexity and uncertainty of the wireless channel, the conventional non-intelligent systems do not cope with the adaptive environment. The soft-computing techniques are preferred over adaptive and non-adaptive systems in time-varying conditions of the channel to approximate and improve real world problems.

Neuro-fuzzy is a hybrid intelligent system that combines the merits of both fuzzy logic and neural networks [23]. The fuzzy inference system (FIS) is useful for imprecise, uncertain information and complex-ill based systems and incorporates human experience based on *if-then* rules in decision-making models [24]. In a fuzzy system, the designer uses fixed membership functions based on human prior knowledge. However, the fuzzy logic membership functions are done by trial and error and have lack of learning abilities. The neural network that resembles human brain, has the capability for learning, optimization abilities and adapt themselves to behave with the changing environment [24]. The neuro-fuzzy logic uses back propagation learning technique of neural networks to train and automatically update membership functions of the fuzzy logic.

Neuro- fuzzy logic for training process

In this research work a special neuro-fuzzy method termed Adaptive Network based Fuzzy Inference System (ANFIS) is used as the model in our proposed algorithm. The architecture of the ANFIS used to maximize the spectral efficiency is shown in figure 2. It consists of five layers corresponding to various functions. The proposed model is trained with SNR, BER, coding rate and modulation order as inputs and data rate as an output which are generated from simulations of the OFDM system using the parameters given in table 1.

The range of fuzzy variables for the BER input values given by 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3} and 10^{-2} should be spaced equally and be quantifiable. To get this a logarithmic operation is performed as given in the following equation.

$$\begin{aligned} BER &= \log_{10} 10^{-p},\ p = 2,3,..,6 \\ BER &= -p \end{aligned} \qquad (4)$$

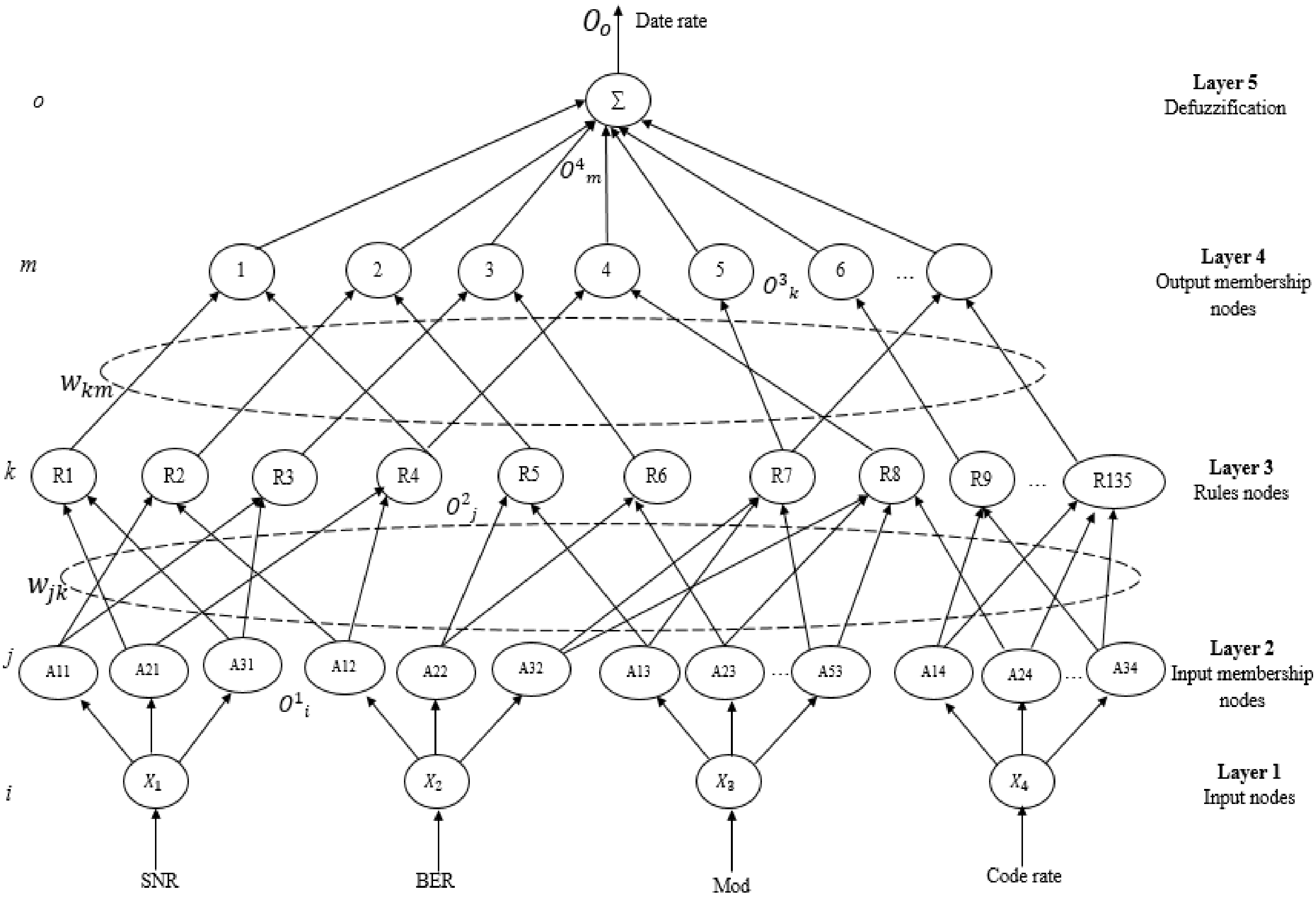

Figure 2: ANFIS architecture

In this neuro-fuzzy proposed system, 135 first order Sugeno-type fuzzy inference rules have been constructed as follows:

The general rule:

IF x_1 is A_{i1} AND x_2 is A_{i2} AND x_3 is A_{i3} AND x_4 is A_{i4} THEN $f_i = p_i x_1 + q_i x_2 + t_i x_3 + s_i x_4 + r_i$ (5)

The specific rules:

IF x_1 is A_{11} AND x_2 is A_{12} AND x_3 is A_{13} AND x_4 is A_{14} THEN $f_1 = p_1 x_1 + q_1 x_2 + t_1 x_3 + s_1 x_4 + r_1$ (6)

IF x_1 is A_{21} AND x_2 is A_{22} AND x_3 is A_{23} AND x_4 is A_{24} THEN $f_2 = p_2 x_1 + q_2 x_2 + t_2 x_3 + s_2 x_4 + r_2$ (7)

where:

- p_i, q_i, t_i, k_i and r_i are the design parameters which are calculated during the training process,
- f_i are the outputs within the fuzzy area specified by the fuzzy logic rules,
- A_{ij} are the fuzzy sets/membership functions for each input parameters, and
- x_i are input parameters to the neuro-fuzzy.

The generalized bell membership function is used to represent for each fuzzy set variables and is given by:

$$\mu_{A_i}(x) = \frac{1}{1 + (\frac{x - c_i}{a_i})^{2b_i}} \quad (8)$$

where x is the input and $\{a_i, b_i, c_i\}$ is the premise parameters set that define shapes of membership functions

The output (data rate) of the neuro-fuzzy system is expressed as:

$$O = \frac{\sum_i \mu_{\mathrm{A_i}}(x) f_i}{\sum_i \mu_{\mathrm{A_i}}(\mathrm{x})} \quad (9)$$

The output of the neuro-fuzzy system selects the desired coding rate and modulation order pair to maximize the spectral efficiency while meeting a target QoS. In the proposed neuro-fuzzy model, a hybrid learning optimization technique is used to automatically adjust the membership functions and optimize the design parameters.

A Sugeno type fuzzy inference system with four inputs and one output is shown in figure 3. The input parameters particularly BER, SNR and code rate are having each three membership functions namely *low, medium* and *high*. For the modulation order input variable, five membership functions namely *very low, low, medium, high,* and *very high* are being considered. The output of the proposed model has only one membership function i.e. *data rate or spectral efficiency*.

The proposed scheme rule editor and rule viewer is shown in figure 4 and figure 5 and these give a better description of all fuzzy rules. Surface views for BER vs SNR and Mod vs code rate of the neuro-fuzzy system is also shown in figure 6 and figure 7 respectively. These surface views dictate the smoothness and correlation between input variables to select the desired output at a particular time.

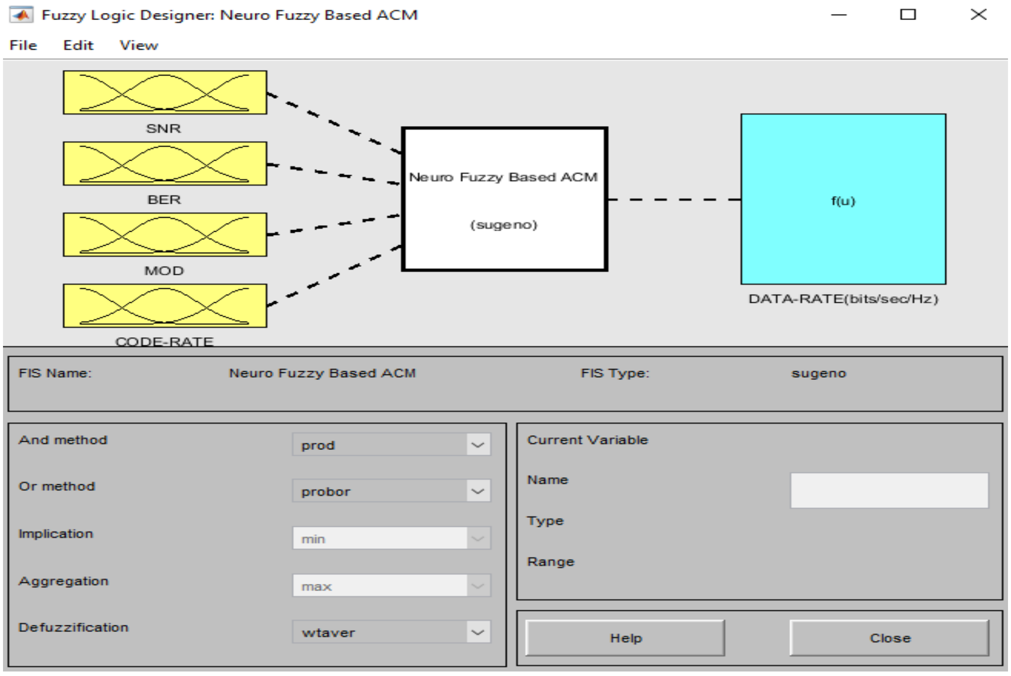

Figure 3: Sugeno-type FIS with 4 inputs and one output

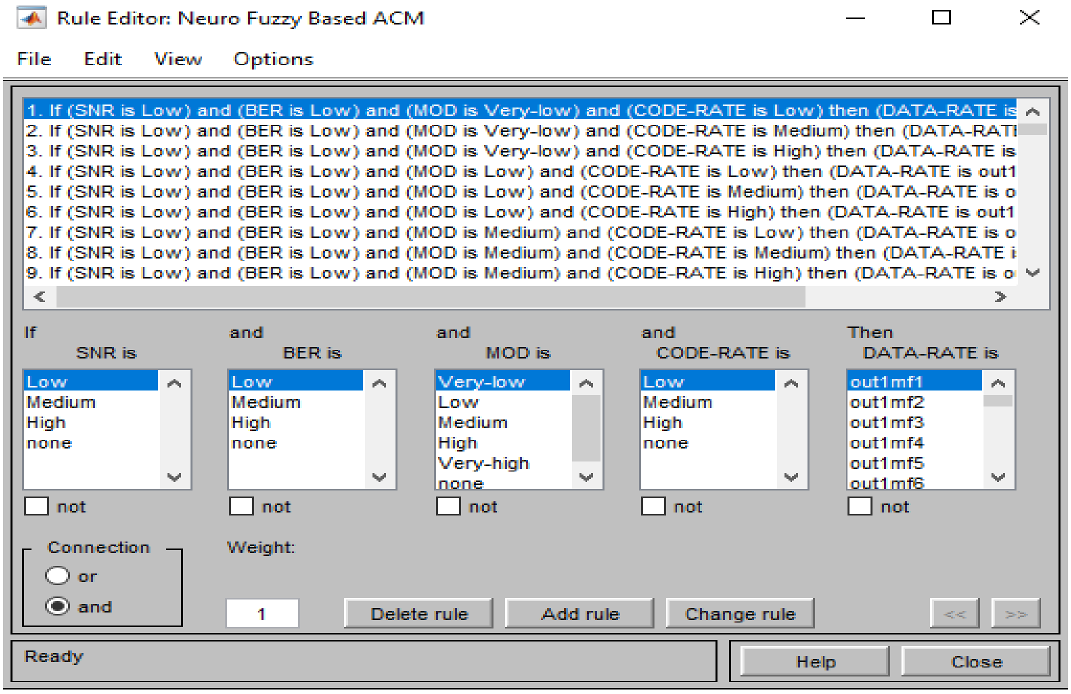

Figure 4: Rule editor of fuzzy inference system

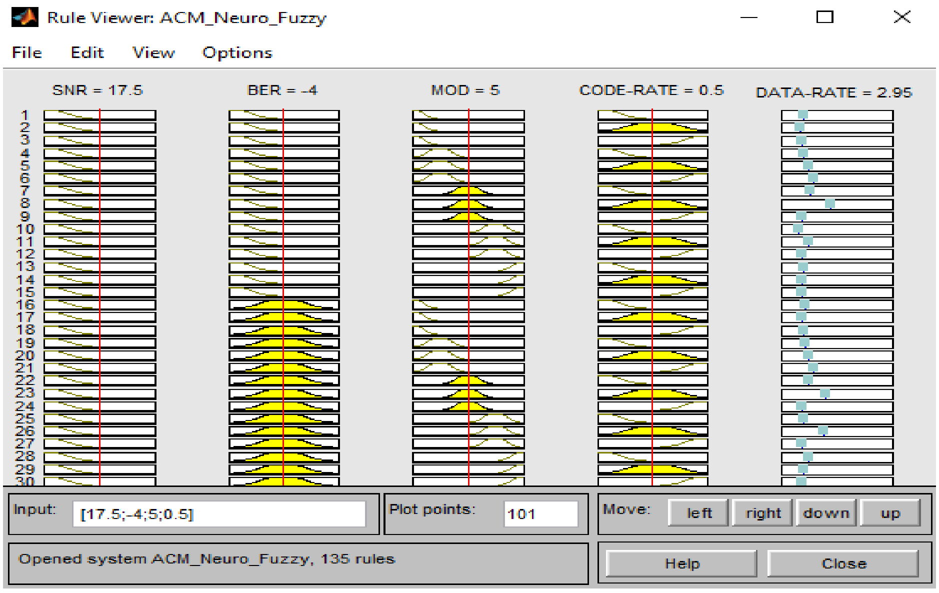

Figure 5: Rule viewer of fuzzy inference system

Figure 6 indicates data rate is maximized by increasing SNR. In addition to this, for a poor QoS the spectral efficiency is higher compared with a low target BER. For a BER of 10^{-2} and SNR of 35dB, a data rate of 6.75 bits/sec/Hz can be achieved. Data rate can also be increased by increasing the modulation order and coding rate as shown in figure 7.

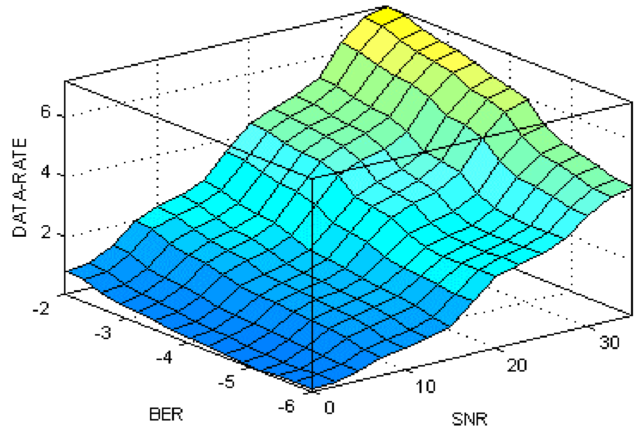

Figure 6: Surface view for BER vs SNR

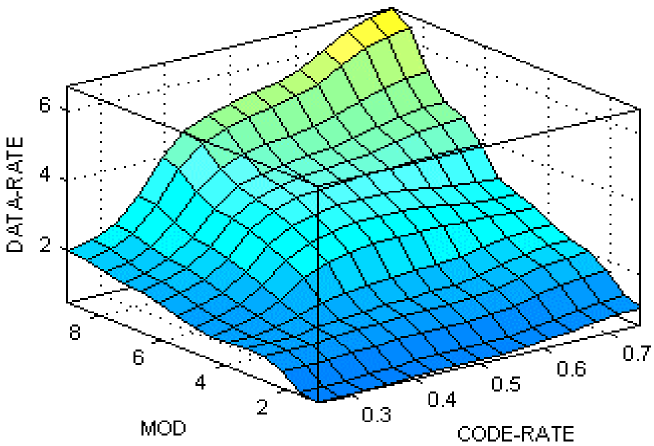

Figure 7: Surface view for MOD vs code rate

SIMULATION RESULTS

The proposed neuro-fuzzy controller based adaptive modulation and coding scheme for OFDM system is simulated in MATLAB environment and compared to the existing models. Figure 8 shows the results of neuro-fuzzy based adaptive coding and modulation for different target quality of services such as 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3} and 10^{-2}. For a fixed quality of service, higher data rate can be obtained by increasing SNR. For a low QoS, higher spectral efficiency can be achieved compared to high QoS at high SNR. Thus, increasing the QoS reduces the data rate that can be transmitted.

Capacity for the Shannon upper limit is compared to upper and lower bounds of the neuro-fuzzy based ACM as shown in figure 9. At 20dB signal-to-noise ratio, a data rate of 6.8, 4.5 and 2.2 bits/sec/Hz can be achieved for Shannon capacity, neuro-fuzzy based ACM for QoS 10e-2 and 10e-6 respectively.

Figure 10 shows the performance comparison of the proposed neuro-fuzzy based adaptive coding and modulation to neural networks, fuzzy logic system [19, 20, 21], switching threshold based adaptive modulation [25], adaptive coded modulation and non-adaptive techniques [11]. The simulation results show that the proposed scheme perfoms better than the other techniques in terms of data rate or spectral efficiency.

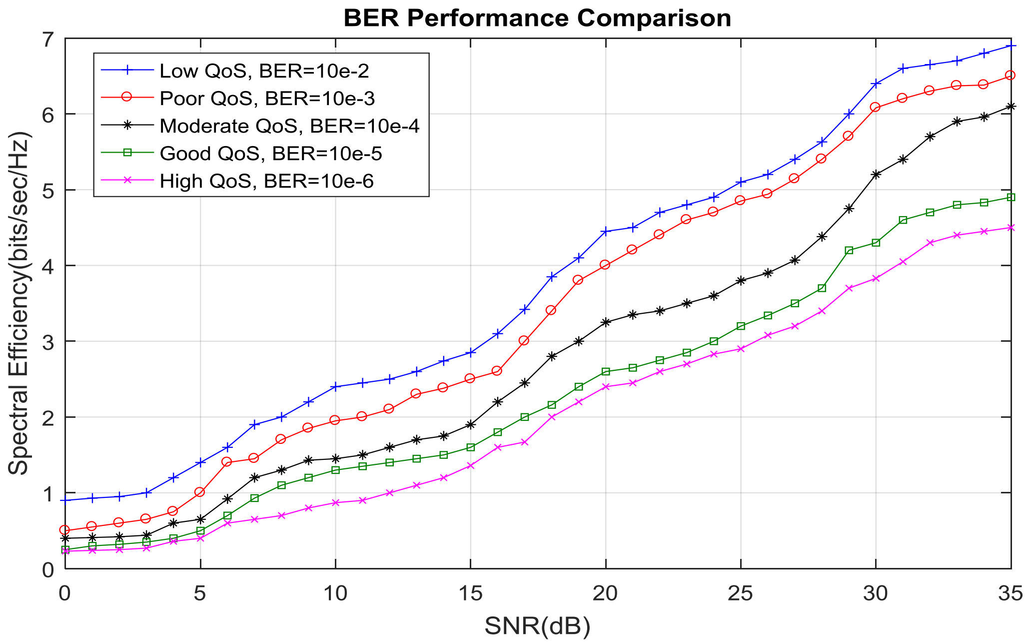

Figure 8: Neuro-fuzzy based performance comparison

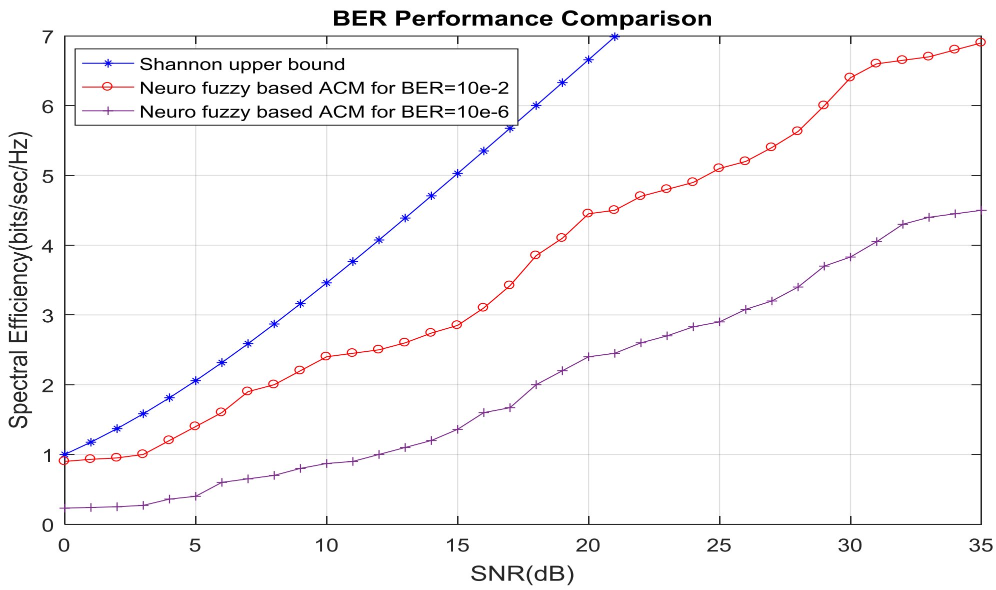

Figure 9: Comparsion of proposed lower and upper bounds scheme to Shannon capacity

Table 2 shows data rate comparison of the proposed scheme to different existing models for SNR 5dB, 15dB, 25dB and 35dB. At 35dB SNR, a neuro-fuzzy based adaptive coding and modulation reveal a superiority in spectral efficiency of 0.15, 0.6, 1.4, 2.4, and 2.9 bits/sec/Hz compared to neural networks based ACM, fuzzy logic baased ACM, switching threshold based adaptive modulation, adaptive coded modulation and non-adaptive techniques respectively.

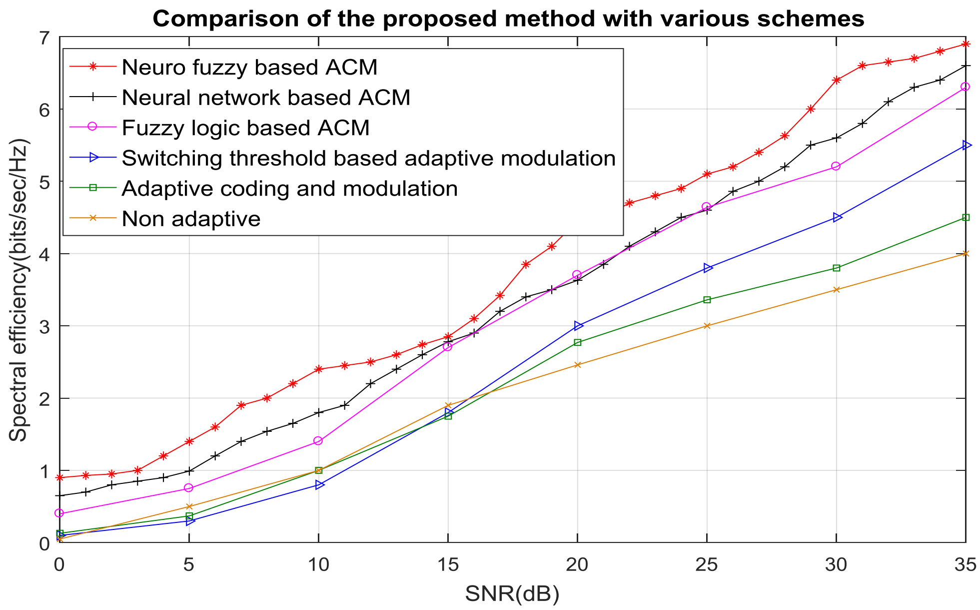

Figure 10: Performnace comparison of proposed model with varios schemes for target QoS 10e-2 and fixed transmit power

Table 2: Data rate (bits/sec/Hz) comparison

Schemes	5dB	15dB	25dB	35dB
Neuro-fuzzy based ACM	1.4	2.85	5.1	6.75
Neuro networks based ACM	0.99	2.78	4.6	6.6
Fuzzy logic based ACM	0.75	2.7	4.64	6.3
Switching threshold based AM	0.3	1.8	3.8	5.5
Adaptive technique	0.37	1.75	3.36	4.5
Non-adaptive methods	0.5	1.9	3	4

CONCLUSION

In this research work, a neuro-fuzzy based adaptive coding and modulation for performance improvement in OFDM wireless systems is proposed and compared to other models and techniques. The performance comparison of spectral efficiency against SNR is done. By using the learning capability of the neuro-fuzzy logic, the network is trained by the real data values that include SNR, BER, modulation order and code rate as inputs and data rate as output. This manual data is generated from simulation of the OFDM system for different coding rate and modulation schemes. As an efficient control mechanism, a neuro-fuzzy logic responds to an adaptive environment to decide the desired coding rate and modulation order to enhance the system performance. By analyzing MATLAB simulation results, it is shown that the neuro-fuzzy system performs better compared to various schemes such as fuzzy logic and adaptive techniques to maximize the spectral efficiency with an acceptable QoS.

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