# Adaptive Modulation based Link Adaptation for High Speed Wireless Data Networks using Fuzzy Expert System

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## ABSTRACT
With drastic increase in demand of high speed data services, achieving better performance of high speed wireless data networks becomes a challenging task because of limited available spectrum and uncertain nature of wireless communication link. Adaptive modulation based link adaptation is one of the solutions to this problem which predicts the efficient modulation technique among the available modulation techniques depending upon state of channel to ensure high performance of data networks. In this paper, Fuzzy Expert System has been introduced which chooses efficient modulation technique among QPSK, 8 QAM, 16 QAM, 32 QAM and 64 QAM depending upon SNR, BER values and current modulation type. This system gives satisfactory results for prediction of better modulation technique among others to implement adaptive modulation based link adaptation which further enhances the performance of high speed wireless data networks by ensuring error free delivery and high spectral efficiency.

## General Terms
Adaptive Modulation, Link Adaptation, Spectral Efficiency

## Keywords
QPSK, QAM, SNR, BER, Fuzzy Expert System

## 1. INTRODUCTION
In the era of information evolution, there is drastic rise in internet users over recent years. So this is a challenging task for internet service providers to cop up the requirement of high speed data services by enormous number of users over limited frequency spectrum. High speed wireless data systems such as WCDMA based High Speed Downlink Packet Access (HSDPA), requires robust and spectrally efficient communication techniques for transmission of data through noisy and fading channels. One of the way of achieving high data rate is to increase allocated bandwidth. But this way is very expansive because of limited available spectrum band which is being used by large number of communication systems. One more barrier in high speed wireless communication is unreliable wireless link suffering from Rayleigh fading which reduces the error performance in fading environment. Therefore, over the last few years, research community is in the progress of developing several techniques to improve spectral efficiency for serving high data rate requirement over fading channels within the given bandwidth. Link adaptation is one the techniques [1], [2], [10].

Link adaptation is also called Adaptive Modulation and Coding. In modern high speed wireless data networks, link adaptation is the process of matching of the technique of modulation, and/or coding rate to the conditions on the wireless communication channel and making necessary changes in modulation and coding depending nature of the channel which may be noisy or clear [3]. Adaptive modulation technique requires some information about the nature of communication channel such as signal to noise ratio (SNR), Bit error rate (BER) etc. at the transmitter side, which is provided through feedback mechanism in order to increase the overall performance of wireless data network in terms of spectral efficiency and error free delivery of data at high speed [2], An increase in SNR or increase in BER leads to choice of higher order modulation technique such as 16 QAM, 32 QAM or 64 QAM and decrease in SNR leads to choice of lower order modulation technique such as QPSK or 8 QAM. This is because of the fact that for higher value of SNR, chances of packet loss are reduced, so by choosing higher order modulation, spectral efficiency can be further enhanced. But on the other side, if SNR is low, then there may be chances of variation in phase of above mentioned higher order modulation techniques because of very small phase difference between adjacent phases, which may lead to distortion or loss of received data packets. Therefore, lower order modulation techniques are mainly preferred in case of lower value of SNR [2], [4], and [5].

In this research paper, a Fuzzy Expert System has been introduced for performing the task of adaptive modulation in order to provide efficient link adaptation. Different types of digital modulation techniques which are being considered in this paper are QPSK, 8 QAM, 16 QAM, 32 QAM and 64 QAM. In fuzzy inference system, SNR, BER and Current Modulation are taken as input parameters which are used to decide the new modulation technique which is going to improve spectral efficiency and ensures error free delivery of data packets.

## 2. LITERATURE SURVEY
In paper [2], Zalonis et al. has studied the problem of link adaptation using adaptive modulation and coding for multiple antenna OFDM system in case of noisy channel. They have given an accurate packet error rate prediction with channel estimation errors on the basis of extrinsic information transfer analysis. In this method, Gaussian approximation has been used to characterize the output of the detector and decoder. They have also discussed approaches for searching and selecting the best modulation and coding scheme for the link adaptation algorithm.

In paper [4] Parminder Kaur et al. have discussed that adaptive modulation systems are better than fixed modulation systems because these systems change its modulation technique according to present modulation values. Authors have proposed an adaptive modulated OFDM system based on Back Propagation Neural Network by taking into consideration SNR and BER Parameters and then evaluating the accuracy of this system on the basis of number of neurons in BPNN and mean square error. But in this research work, initial data set having known best modulation techniques on the basis of known value of SNR and BER is required which is a difficult task.

In Paper [5], Parminder Kaur et al. have discussed adaptive modulated Orthogonal Frequency Division Multiplexing (OFDM) system based on Radial Basis Function and then performance of the system is evaluated on the basis of mean square error and classification accuracy is evaluated according to the number of neurons in RBF network. But again this system will make decision about best modulation on the basis of Data set of known inputs and known best output and this type of data set is very difficult to produce and also reliability of this type of data set in different fading channel environments is doubtful.

In paper [6], Iftekhar Alam et al. have discussed various adaptive modulated MC-CDMA systems in Rayleigh fading channel. They have considered various digital modulation techniques such as M-ary PSK, M-ary QAM, M-ary MHPM, M-ary CPM, and GMSK with varying bit-duration-bandwidth product. The results of their paper show that the dynamic switching of the modulation orders can enhance the system performance and capacity per given bandwidth of fading channel with the expected BER performance. But fuzzy logic system has the capacity of making the adaptive modulation much easier and more effective.

## 3. FUZZY EXPERT SYSTEM

In the year of 1965, Dr. Lotfi Zadeh, a professor of mathematics from U.C. Berkeley, proposed the fuzzy theory [7]. Fuzzy logic is a valuable tool which is basically used to solve highly complex real time problems where a mathematical modelling is very difficult to achieve. Fuzzy logic also helps in reducing the complexity of existing solutions as well as increase the accessibility of control theory.

Fuzzy expert system, also known as Fuzzy Inference system suitable for tasks involving logic has been proposed as compared to classical crisp set theory. The "fuzzy set" has been employed to expand classical sets, which are characterized by some margins for modelling of real time problems. Fuzzy logic provides a degree of flexibility for each object which belongs to a particular set. This quality is realized by membership functions which give fuzzy sets the capacity of modeling linguistic, fuzzy expression [8].

Fuzzy logic based fuzzy expert system is IF-THEN rule based system in which a set of rules represents a control decision mechanism to correct the effect of certain cause used for many systems. The configuration of fuzzy logic based system into three parts they are, Fuzzification, Interface Mechanism and Defuzzification. Fuzzification process is used to convert classical data or crisp data into fuzzy data or Membership Functions (MFs). Fuzzy Inference System combines membership functions with the control rules to derive the fuzzy output. Defuzzification is the process of using different methods to calculate each associated output and put them into a table: the lookup table and then to pick up the output from the lookup table based on the current input during an application . Fuzzy Expert System has been shown in the following figure.

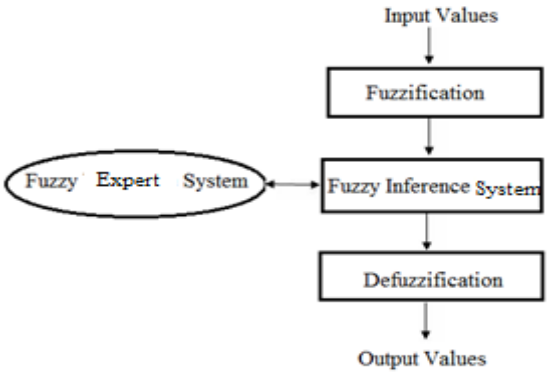


**Fig1: Fuzzy Expert System**

## 4. RESULT ANALYSIS

In this research work, Fuzzy inference system which is termed as Fuzzy Expert System, has been implemented using MATLAB. For this research work of link adaptation based adaptive modulation has been performed by using MATLAB 2014b on windows 8.1 operating system machine having Intel Core I3 processor. For this system, three input variables are taken into consideration which are Signal to Noise Ratio (SNR), Bit Error Rate (BER) and Current Modulation and output of the system is New Modulation. Fuzzy Inference System model for link adaptation is shown in figure 2.

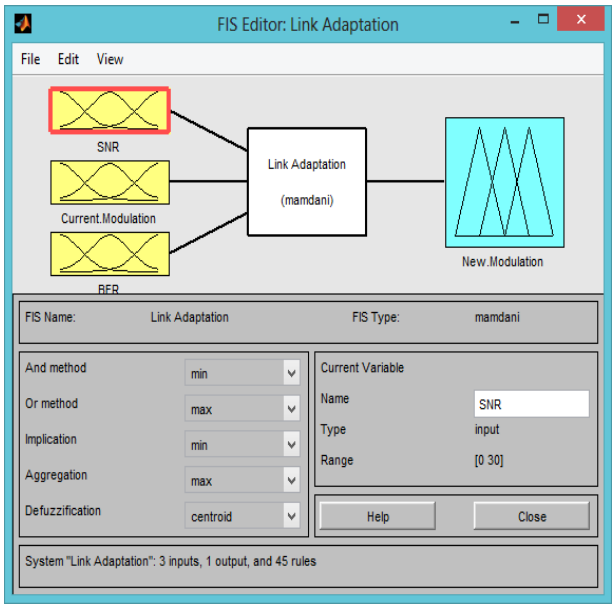


**Fig: 2 Link Adaptation: Fuzzy Inference System**

The input and output variables of above mentioned Fuzzy Inference System are discussed below:

- SNR: This input variable is most important factor for describing noisy or clear nature of wireless communication channel which is mainly used to make decision about new modulation technique in order to implement adaptive modulation. In this research work, a total 0 dB to 30 dB SNR range has been taken into consideration which is divided into three membership functions: Low ranging up to 17 dB, Medium ranging up to 23 dB and high ranging above 23 dB [10]. If value of

SNR is going to be increased, then there is the possibility of choosing higher order modulation technique so as to increase spectral efficiency. If SNR value is low, then lower order modulation is the favorable choice because with increase in channel noise, there is the possibility of distortion in higher order modulated received signal because of lesser phase difference and amplitude difference in adjacent levels of higher order modulation techniques such as 32 QAM or 64 QAM. In case of medium values of SNR, there may be no change in modulation technique. SNR input variable along with its membership functions is shown in following figure.

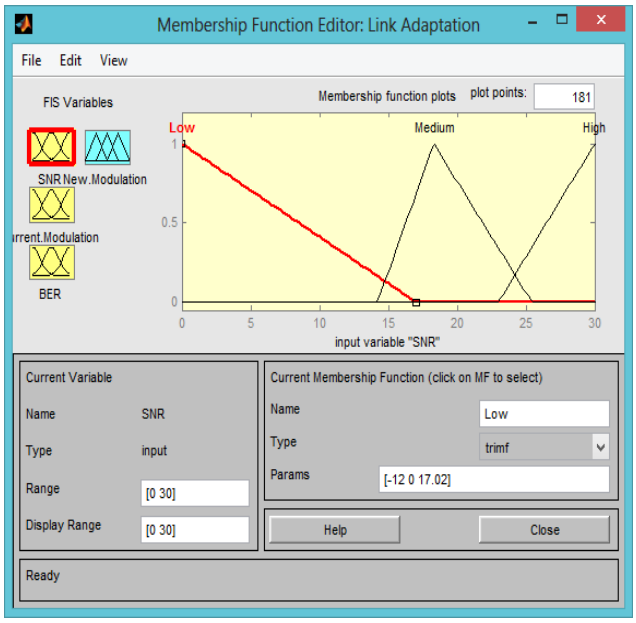


**Fig 3: Signal to Noise Ratio (SNR) input variable along with its membership functions**

- BER: This is the second variable which is helpful in decision making about best modulation technique in the implementation of adaptive modulation for link adaptation. This variable is also divided into three membership functions: LOW, MEDIUM and HIGH. If BER is having high value, then it is favorable to choose higher order modulation technique so as to reduce the value of BER. If BER is having medium value, then it is still favorable to select higher order modulation so as to further improve the performance of high speed wireless data networks. In case of low value of BER, there is no need to change existing modulation technique. BER input variable along with its three membership function is shown in following figure.

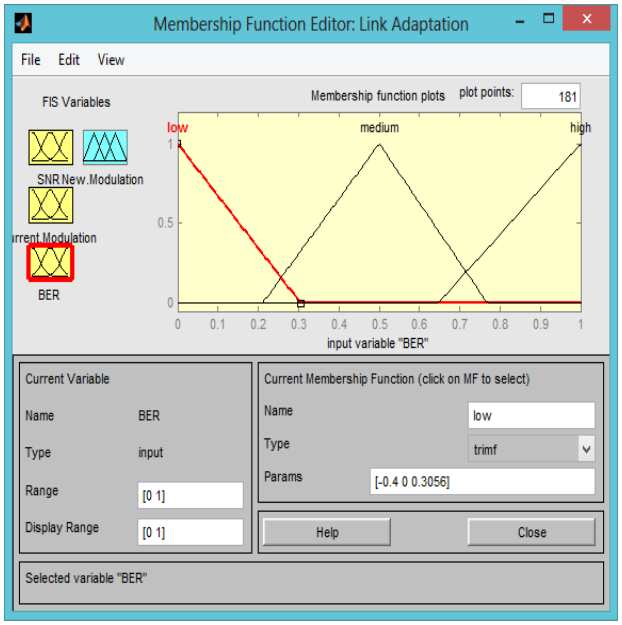


**Fig 4: Bit Error Rate (BER) input variable along with its membership functions**

- Current Modulation: This input variable describes different type of modulation techniques used in wireless data networks. In this research work, only five modulation techniques have been taken into consideration which are Quadrature Phase Shift Keying (QPSK), 8 Quadrature Amplitude Modulation (8 QAM), 16 QAM, 32 QAM and 64 QAM. As the order of modulation technique is increasing, spectral efficiency of the system is also going to be increased. For example, in QPSK, spectral efficiency is 2. But in case of 64 QAM spectral efficiency is 6. Current Modulation input variable along with its five membership functions representing different modulation techniques as 0,1,2,3 and 4 is shown in following figure.

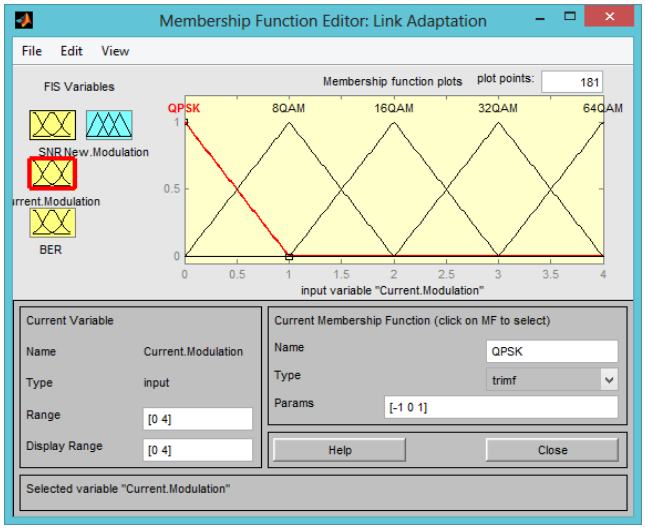


**Fig 5: Current Modulation input variable along with its membership functions**

- New Modulation: This is the output variable which describes favorable modulation technique for giving better performance of high speed wireless data networks

depending upon above mentioned input variables. In this variable , again five different type of modulation techniques are taken into consideration which are QPSK, 8 QAM, 16 QAM, 32 QAM and 64 QAM. Choice of best modulation technique among others depending upon SNR and BER values of network which represent instantaneous characteristics of the channel leads to implementation of adaptive modulation which in turn leads to efficient link adaptation for better performance of wireless data networks in fading or clear channel environments. New Modulation output variable along with its five membership functions representing efficient modulation technique for implementing adaptive modulation is shown in following figure.

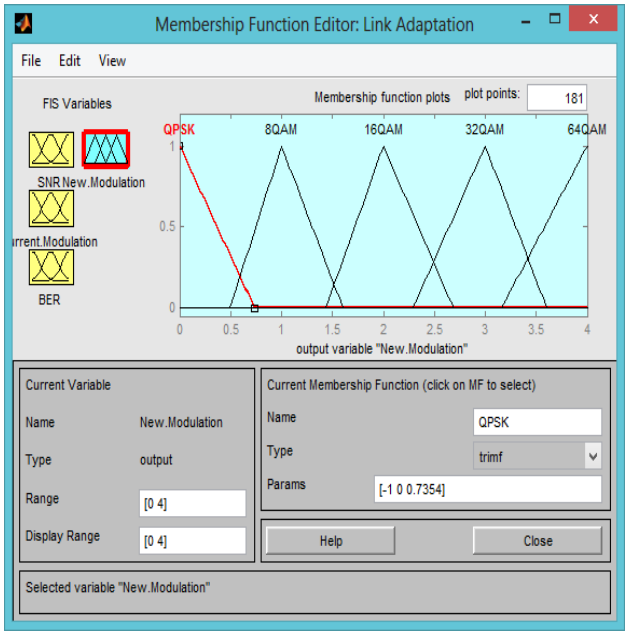


**Fig 6: New Modulation Output variable along with its membership functions**

Figure 7 shows Fuzzy IF-THEN rules modelled in Fuzzy Inference System deciding efficient modulation technique depending upon nature of channel. The unreliable nature of wireless communication channel can be properly represented by SNR and BER information obtained at the receiver side which can be feedback to transmitter part so as to implement adaptation modulation in order to obtain link adaptation for better performance of wireless data networks.

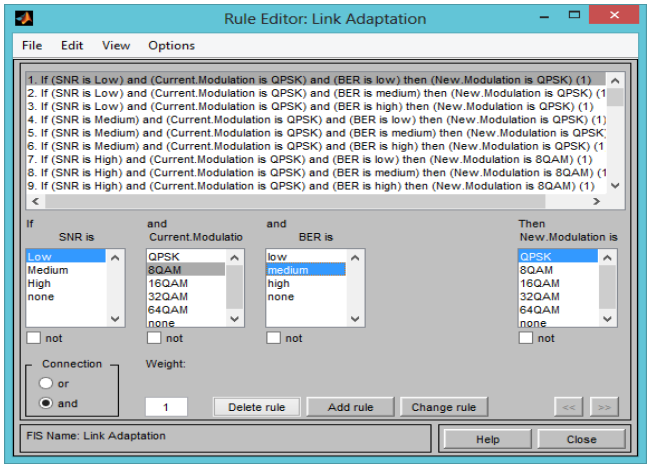


**Fig 7: Fuzzy IF-THEN rules**

Figure 8 shows surface viewer diagram by taking into consideration two input variables SNR and Current modulation for output variable New Modulation. This is graphical representation indicates degree of randomness of IF-THEN rules. This representation shows that all different possible combinations are properly described in this fuzzy inference system. Similarly combination among other variables also represents high degree of variability in rules formation.

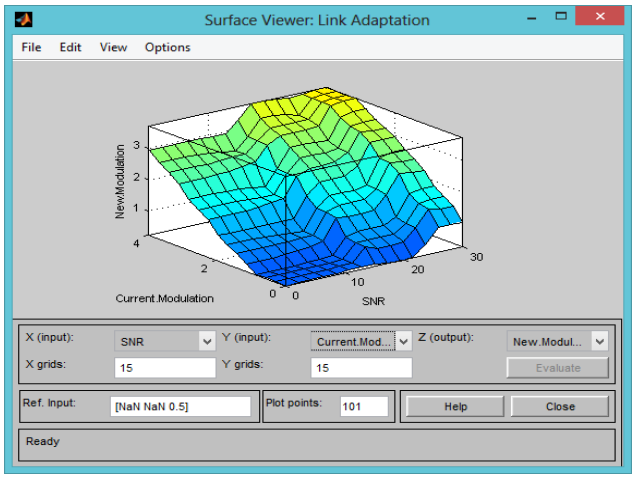


**Fig 8: Surface viewer representing SNR and current modulation input variable**

Results obtained from this fuzzy exert system by taking into consideration random values of SNR, BER and Current modulation technique are shown in following table.

**Table 1: Evaluation of Fuzzy Expert System**

| Sr. No. | SNR (in dB) | BER | Current Modulation | New Modulation |
|---|---|---|---|---|
| 1 | 3 | 0.7 | 1 (8QAM) | 0 (QPSK) |
| 2 | 27 | 0.9 | 2 (16QAM) | 3 (32QAM) |
| 3 | 15 | 0.3 | 3 (32QAM) | 3 (32QAM) |
| 4 | 22 | 0.5 | 4 (64QAM) | 4 (64QAM) |
| 5 | 18 | 0 | 1 (8QAM) | 0 (QPSK) |

Now the input variables and corresponding results mentioned in above table are verified manually, and it reveals that Fuzzy expert system modelled in this paper gives quite satisfactory results which match with the corresponding predictions of manual verification. So, Fuzzy Expert System gives very good response for implementation of adaptive modulation in order to obtain link adaptation of uncertain communication channel so as to enhance the performance of the high speed wireless data networks in terms of error free delivery and spectral efficiency.

## 5. CONCLUSION AND FUTURE SCOPE

In this research paper, Fuzzy expert system has been implemented for performing adaptive modulation in order to obtain link adaption which leads to error free delivery of data and ensure high spectral efficiency. In this system, SNR, BER and Current Modulation are taken as input variables which are used to decide best modulation technique for improving performance of the wireless data network using fuzzy IF-

THEN rules. Results reveal that Fuzzy expert system works quite well for prediction of better modulation technique among others to implement adaptive modulation based link adaptation which further enhances the performance of high speed wireless data networks by ensuring error free delivery and high spectral efficiency.

In this research paper, only two input variables SNR and BER are taken into consideration in order to examine the uncertain behavior of communication channel. There is the possibility of including other parameters such as forward error correction code rate etc. so as to improve the results of fuzzy inference system. Secondly, in this research work, only five modulation techniques have been considered. Other higher and lower order modulation should also be taken into account for provide the benefit of adaptive modulation to large number of applications.

## 6. REFERENCES

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