Adaptive Code Modulation for Rainfall Fade Mitigation in Ethiopia

Eyob Mersha Woldamanuel

A Thesis submitted to
The department of Electronics and Communication Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electronics and Communication Engineering

Office of Graduate Studies
Adama Science and Technology University

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I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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LIST OF ABBREVIATIONS

ACM	Adaptive Coding and Modulation
ANFIS	Adaptive Network Fuzzy Inference System
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CSI	Channel State Information
DE	Differential Evolution
DLPC	Down-Link Power Control
DPSK	Differential Phase Shift Keying
EEPC	End-to End Power Control
EHF	Extremely High Frequency
FD	Frequency Diversity
FEC	Forward Error Correction
FIS	Fuzzy Inference System
FMT	Fade Mitigation Technique
FRBS	Fuzzy Rule-Base System
GHz	Giga Hertz
GRBF-NN	Gaussian Radial Bases Function -Neural Network
I/O	Input /Output
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Recommendations
LOS	Line-of-Sight
MCP	Modulation Code Pair

MF	Membership Function
ModCod	Modulation and Coding
MPSK	M-ary Phase Shift Keying
MQAM	M-ary Quadrature Amplitude Modulation
NN	Neural Network
OBBS	On Board beam Shaping
OFDM	Orthogonal Frequency Division Multiplexing
OPV	Optimum Power Vector
PAM	Phase Amplitude Modulation
PER	Packet error Rate
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift keying
RBFNN	Rule-Base Fuzzy Neural Network
RIA	Rain Induced Attenuation
SatD	Satellite Diversity
SD	Satellite Diversity
SHF	Super High Frequency
SNR	Signal-to Noise Ratio
ULPC	Up-Link Power Control

ABSTRACT

The massive demand for efficient, and reliable wireless communication systems has motivated researchers, and network designers to study communication systems that operate at microwave and millimetric wave bands. This is due to congestion in the lower frequency spectrum and increasing demand for large bandwidth and high channel capacity. However, the reliability of radio communication systems at the higher operation frequency spectrum can be affected by various atmospheric elements. Of all atmospheric constituent, rainfall is the major cause of impairment at higher frequency band bringing about scattering, attenuation and depolarization of signals at the receiver. Rain attenuation, is considerably noticed above 7 GHz and 10 GHz in tropical equatorial and temperate climates, respectively. It causes attenuation in the transmitted signal and reduction of the link availability. In order to satisfy the Quality of Service QoS specifications and to achieve high levels of link availability, rain fade counter measures are required. Adaptive coding and modulation technique (ACM) is one of the several Fade Mitigation techniques employed to mitigate the effects of time-varying channel conditions imposed by fading, interference, and noise on wireless communications. The International Telecommunication Union -Recommendation ITU-R, through Recommendation P 530-16 and P 618-13, provides basic Line-of-Sight (LOS) link design assumptions based on propagation prediction methods which are not suitable for tropical regions and at high rainfall rate since average radius of raindrop in tropical region is greater than that in non-tropical and data for ITU model is based on data collected from temperate regions. Thus, ITU-R recommends to use locally measured rain data to predict the rain attenuation for this reason. Unfortunately, a rain fade mitigation technique based on local rain data has not been adequately studied. This situation is more prevalent when it comes to African equatorial and tropical countries. In addition to this, since the condition of the wireless channel is varying with time, an intelligent adaptive technique, which is good in decision making, is required. In other words, due to complexity, uncertainty and adaptive nature of the wireless channel, the conventional non-intelligent systems cannot cope with an adaptive environment. Soft computing techniques such as fuzzy logic, neural networks, and neuro-fuzzy systems are preferred over the adaptive and fixed coding and modulation techniques in decision-making. In this thesis, a one-minute rain rate data collected using a measuring device installed at Jimma University,Ethiopia is used to determine the rain attenuation. Then, based on this calculated rain attenuation Neuro-

Fuzzy based Adaptive Coding and Modulation technique is employed to mitigate rain fade in a particular microwave link between Jimma and Muja.SNR,BER,modulation orde and coding rate are the input parameters that are used to enhance ACM using Neuro-Fussy based decision making system. Furthermore, the performance of this Neuro-Fuzzy based adaptive coding and modulation scheme is compared with non-adaptive technique, and fuzzy-based adaptive modulation and coding technique.The rain data analysis depicts that the signal-to-noise ratio at clear sky is 32.5dB for this particular microwave link.Where as ,as the rain rate is above 130 mm/hr ,signal-to-noise ratio drops to 0dB and network outage will occurred.Thus,lower order modulation scheme with lower coding rate,such as 4QAM-1/3,8QAM-1/4,16QAM-1/4, is better in maintaining link availability.However,when the channel is not affected by rain spectral efficiency is improved by utilizing larger constellation size modulation scheme such as 256QAM,512QAM and 1024 QAM with higher coding rate like 3/4. .In addition to this, MATLAB simulation result showed that adaptation of channel condition using Neuro-Fuzzy based adaptive coding and modulation is better than fuzzy logic based adaptation and threshold adaptive coding and modulation techniques.

Key Words:ITU-R, Rain Attenuation, fade Mitigation Tecchnique,Adaptive Coding and Moddulation ,Spectral Efficiency,Fuzzy Logic based ACM, Neuro-Fuzzy bassed ACM

CHAPTER 1

INTRODUCTION

This chapter provides a brief introduction to the background of the study, problem statement and objectives of the research work. In addition, significance, scope and organization of the thesis are also presented.

1.1 Background

The enormous need for high speed, reliable and smooth connectivity of high capacity, wireless communication systems has motivated researchers, communication engineers and network designers to study communication systems that operate at microwave and millimetric wave bands. This is due to congestion in the lower frequency spectrum and increasing demand for large bandwidth and high channel capacity to accommodate ever growing customer services [1, 2]. However, the reliability of radio communication systems at the higher operation frequency spectrum can be affected by various atmospheric elements such as rainfall, temperature, pressure, humidity and gases [1, 3]. Of all atmospheric constituent, rainfall is the major cause of impairment at higher frequency bands bringing about scattering, attenuation and depolarization of signals at the receiver[2–4].

Generally, at frequencies below 7 GHz, excess attenuation due to rainfall and atmospheric gaseous, frozen particles such as snow, ice crystals is very small and can be neglected in radio system design .Rain fade, also referred to rain attenuation, is the dominant factor in path loss variation above 7 GHz and 10 GHz in tropical equatorial and temperate climates, respectively[1, 3, 5]. Attenuation experienced in these areas is caused by considerably higher rainfall rates and bigger size of raindrops compared to other parts of the world [6]. Droplets of rain that are found anywhere along the transmission path in between the transmitter and receiver absorb and diffuse radio frequency. This absorption and diffusion of radio waves cause attenuation in the transmitted signal and reduction of the link availability. Thus,the occurrence of rain along the transmission path is considered as the main impairment factor for microwave system degradation. It limits the transmission distance of radio communication systems and the use of higher frequencies for line-of-sight microwave links and satellite communications. Consequently, awareness of the rain fade at the desired frequency of operation is a critical necessity for the design of a reliable terrestrial and/or earth space communications.

Wireless communications network performance analysis at higher radio frequencies mainly depends on the assessment of rain attenuation. The fade margin, that is, the system gain ensuring the necessary Quality of Service (QoS) against various transmission and other impairments, must be considerably increased to compensate for the severe signal fading occurring at frequencies above 10GHz. The larger fade margins required are not feasible either technically or economically. Under these conditions, it is more difficult for microwave and millimeter band communication systems to satisfy the availability and QoS specifications recommended by the Radio Communications Sector of the International Telecommunications Union (ITU-R)[7].In order to satisfy the QoS specifications and to achieve high levels of link availability, rain fade counter measures are required. The technique used to overcome this problem is known as Fade Mitigation Technique (FMT) [8, 9]. The use of fade mitigation technique to permit operations under lower fade margins is imperative.

Adaptive coding and modulation technique (ACM) is one of the several Fade Mitigation techniques employed to combat the effects of time-varying channel conditions imposed by fading, interference, and noise on wireless communications. The performance of coding and modulation techniques can be enhanced by adapting the transmission parameters such as code rate and modulation order to the time-varying channel conditions. The purpose of this transmission adaption is to increase reliability (reduce BER), spectral efficiency, and conserve the transmitted power. The quality of the channel should be estimated first to identify the best coding rate and modulation order[10].

When the estimated signal-to-noise ratio (SNR) is high, then a higher modulation order with a higher coding rate can be used to increase spectral efficiency[11]. In other words, if the BER is low and SNR is high, a higher coding rate and modulation order such as 3/4 coding rate and 512QAM can be employed. On the other hand, during worst channel condition, lower coding rate and modulation order like QAM4 and 1/4 code rate are used to maintain link availability. Thus, the purpose of adaptive transmission method is to improve the spectral efficiency and transmission link availability by increasing the channel capacity over the communication channel and to reduce the propagation impairment effect such as rain fades and environmental interferences.

In ACM techniques, the desired coding rate and modulation order is selected based on the estimated SNR and/or calculated BER as shown in Figure 1.1. In a wireless communication

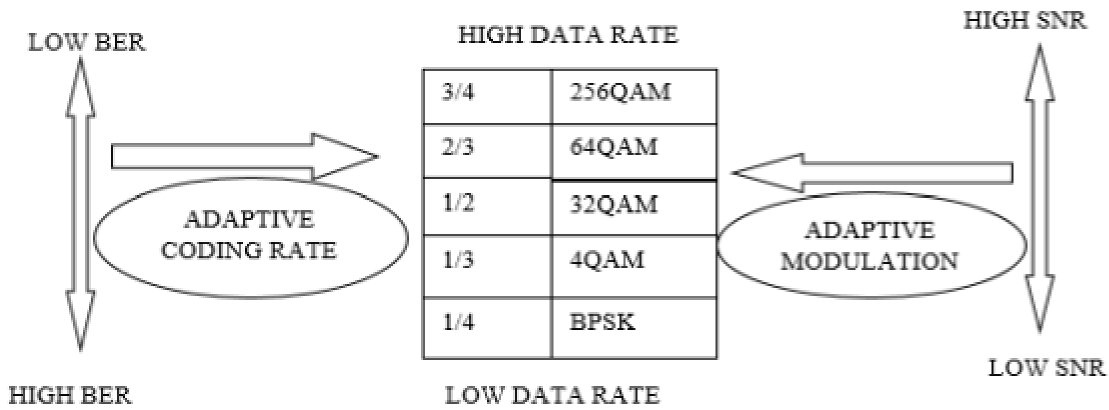

Figure 1.1: Coding and Modulation scheme selection mechanism

system, adapting transmission parameters is done based on the quality of the channel. In a fixed coding and modulation scheme, the communication system uses single coding rate and modulation order so that either spectral efficiency or BER is improved. However, adaptive modulation is advantageous than fixed modulation scheme since it responds to time-varying channel condition by dynamically varying both modulation order and coding rate to maintains good performance (Bit Error Rate) and provide better speed (capacity).

Since the condition of the wireless channel is varying with time, an intelligent adaptive technique, which is good in decision making, is required. In other words, due to complexity, uncertainty and adaptive nature of the wireless channel, the conventional non-intelligent systems cannot cope with an adaptive environment. Soft computing techniques such as fuzzy logic, neural networks, and neuro-fuzzy systems are preferred over the adaptive and fixed coding and modulation techniques in decision-making to approximate and improve real-world problems.

The conventional adaptive coding and modulation techniques use the if-else statements to select the desired modulation order and coding rate based on the received SNR and/or BER.

Nevertheless, the ordinary hardware decision-making techniques have limitations in predicting the exact quality of the channel and selecting the appropriate transmission parameters. Using soft computing technique like fuzzy logic in decision making is a good choice because the ordinary (non -fuzzy) system is controlled by plain if and else. For instance, if for poor SNR range is set to 0 - 3 and input is 3.1 then the input is not considered as poor SNR (But it is poor). If fuzzy logic is used in above case 3.1 is also considered as poor SNR. Hence, enhanced adaptive modulation is obtained by applying Fuzzy logic-based control system. Neuro-fuzzy (N-F) controller combines the advantages of fuzzy logic and neural networks. N-F controller provides automatic adaption procedure to the fuzzy logic controller[12].

Hence, ACM can be varied efficiently with the time changing conditions of the channel by implementing it along with the neuro-fuzzy based approach in decision-making system. In this research work, adaptive coding and modulation technique and its capability are investigated to mitigate rain fade in Ethiopia, which is a tropical country, using measured rain data. In addition to this, a neuro-fuzzy based decision-making system is implemented along with adaptive coding and modulation schemes to improve the performance of single frequency carrier communication systems that takes estimated SNR, BER, modulation order and coding rate as inputs to select the desired modulation order and coding rate as output.

1.2 Statement of the Problem

The radio wave traveling through the lower atmospheric layer of earth is degraded because of the presence of atmospheric particles, such as water vapor, water drops, and the ice particles. The atmospheric gases and rain both absorb and scatter the radio waves and consequently degrade the performance of the microwave link. Microwave and Millimeter-wave (mm-Wave) is todays breakthrough frontier for emerging wireless mobile cellular networks, wireless local area networks, personal area networks, and vehicular communications. However, for tropical countries like Ethiopia, the data link reliability is affected by atmospheric particles. Among these atmospheric constituents, rainfall is the major cause of impairment at higher frequency bands[1].

The ITU-R, through Recommendation P 530-16[5] and P 618-13[13], provides basic Line-of-Sight (LOS) link design assumptions based on propagation prediction methods which are not suitable for tropical regions and at high rainfall rate since average radius of raindrop in tropical region is greater than that in non-tropical and data for ITU model is based on data collected from temperate region of the world [14].It is evident that from research work[2], the rainfall rate values at different percentages of time for various locations of Ethiopia do not correspond to ITU-R classifications. It is therefore imperative that for these regions, experimentally determined parameters are obtained to modify or refine these propagation prediction methods.

Most of the researches that have done on mitigation techniques of rain fade on microwave terrestrial Line-of-Sight communication for tropical regions was based on the ITU-R propagation and prediction method which is not practical for the reason mentioned above. This implies that a rain fade mitigation technique based on local rain data has not been adequately studied. This situation is more prevalent when it comes to African equatorial and tropical countries. Thus, a rain attenuation countermeasure based on local rain data model must be investigated for microwave and millimeter wave radio links especially for African tropical countries like Ethiopia where there are high rainfall rate and intensity. Investigation of mitigation technique of rain fade on microwave and millimeter wave Line-of-Sight terrestrial communication in Ethiopia based on local data is the main motivation to this proposed work.

Even though, several works have been done to investigate mitigation of rain fades in [15-18], most of the studies were focused on satellite links and not based on the local rain data. In addition to this one can encounter several studies in the area of adapting OFDM wireless links using fuzzy and Neuro-Fuzzy techniques[19-21]. However, the adapting capability of soft computing based adaptive coding and modulation technique has not been adequately studied for single frequency carrier communication links. This is also another motivation for this study.

1.3 Significance of the study

This thesis has aimed at making substantial contributions to this topic. Some of the benefits of this research work are listed as follows:

- As have been discussed above, rain attenuation determination in the tropical region needs local rain data. However, there is no enough study in these tropical countries. Thus, this proposed work will be an additional asset in this study area.
- It is crucial to know the atmospheric impairment especially rain attenuation effect for the microwave link designer. Thus, the result of this proposed work can be taken as input before planning to deploy microwave link in Ethiopia.

- The result of this investigation will be useful for microwave terrestrial Line-of-Sight communication researcher.
- The use of artificial intelligence techniques, for instance, neural networks, fuzzy logic, and neuro-fuzzy have shown great potential in adapting time-varying channel conditions for wireless communications. Thus, in this work the neuro-fuzzy system is used to maximize spectral efficiency and improve QoS for a time- varying wireless systems.

1.4 General and specific objectives

1.4.1 General Objective

The main objective of this thesis is to mitigate rain attenuation over Line - of- Sight terrestrial microwave communication using Adaptive Coding and Modulation (ACM).

1.4.2 Specific Objectives

The specific objectives of this proposed thesis are listed below:

- To make an assessment study of the different rain attenuation mitigation technique in tropical regions.
- To determine the rain rate and percentage of exceedance
- To determine specific rain attenuation and total rain attenuation
- To implement Adaptive coding and modulation technique to mitigate the rain fade in Ethiopia using MATLAB simulation software
- To further enhance the adapting capability of ACM by applying the Neuro-Fuzzy system

1.5 Scope of the study

The main focus of this research is to develop a Neuro-Fuzzy system based adaptive coding and modulation for mitigation of rain fades over microwave and millimetric wave radio links in Ethiopia based on locally measured rain data. Perfect knowledge of the AWGN channel is assumed. The research is done to mitigate single frequency carrier radio links. This thesis is limited to developing and simulating a model using MATLAB toolboxes.

1.6 Organization of the thesis

The thesis is organized in the following way: Chapter one presents a brief introduction of the study, the motivation of the study, the significance of the study, objective of the thesis, scope of the work.

Chapter two presents the literature review and brief introduction of rain fade, rain fade mitigation techniques, adaptive coding and modulation techniques. In addition, soft computing-based techniques such as fuzzy logic, neural networks and neuro-fuzzy in relation to adaptive coding and modulation for wireless systems are discussed in this chapter.

In chapter 3 the methodology of proposed neuro-fuzzy based adaptive coding and modulation to mitigate rain attenuation over terrestrial Line- of-Sight radio links are explained.The model used to determine rain attenuation and the procedures included in the model are clarified.Then procedures that are used to implement Neuro-Fuzzy based adaptive coding and modulation scheme are explained briefly.

Chapter 4 present the result and discussion of the simulation results. Performance comparison of the simulation results of the proposed scheme to other existing models such as fuzzy logic and adaptive techniques, and discussion of the results are explained.

Chapter 5 gives the conclusion and recommendation of the thesis.Finally,references that are used in this research work are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Line-of Sight Communication Above 5GHz

Line- of- Sight propagation is considered as the easiest wireless transmission mode. It can also be considered as a microwave radio link in which its transmission path from transmitter to receiver is free from any obstacle[1, 22]. Even though, a satellite link along with its terminals is a Line-of-Sight communication, Line- of- Sight communication is mostly mean terrestrial radio link. In some books, it is termed as hops with a path length ranging from 10 km to 100 km. It offers a broadband telecommunication service with carrier frequency above 900MHz.

A dramatic increase of telecommunication service demand has made the traditional lower frequency usage congested. This crowding of lower frequency band led scientists and network designers to shift their interest from low frequency to higher frequency spectrum usage, more specifically to centimeter and millimeter wave bands[22]. These higher frequency spectrum are suitable for point-to-point and point-to-multi point Line-of-Sight radio links due to their capability to handle higher data rate radio links. However, these frequency spectrum are susceptible to degradation due to the presence of atmospheric particles along its transmission path.

At higher frequencies, frequencies which are found in microwave and millimetric wave bands, the interaction of electromagnetic waves with atmospheric gases and with different metrological phenomena such as hydrometers is increased. This interaction of electromagnetic waves like rain, snow ,and hail cause absorption and scattering of energy which result in transmitted signal attenuation[22].

Fading is defined as “the variation with time of the intensity or relative phase, or both, of any of the frequency components of a received radio signal due to changes in the characteristics of the propagation path with time." During a fade the received signal level(RSL) decreases. This results in a degradation of CrN, thus a reduction of signal-to-noise ratio in the demodulated signal,and, finally, an increase in noise in the derived voice channel. On digital systems, fading degrades the BER, causing burst errors.The fading or attenuation caused by rainfall is the main topic of this research work which is discussed briefly in subsequent sections.

2.2 Rainfall Attenuation

From all atmospheric particles, rainfall is the major natural phenomenon which cause sever propagation degradation in the microwave and millimetric-wave bands[1, 23-25].The severity of rain fade becomes considerable at millimeter-wave frequencies. This is due to the comparable size of the raindrops with the wavelength of these spectrum frequencies. Since the rain intensity and the size of rain drop differ from place to place, the frequency at which rain attenuation become sever is dependent on the geographical area. This is the reason why several scientists have not common starting frequency at which rain fade become catastrophic for signal transmission. In [26] 5GHz is the frequency at which rain fade becomes a problem and 20-30GHz a major propagation impairment depending on the location and link distance. Some put 10GHz [22, 23, 27, 28] as the lower frequency margins for rain become an important factor in the design of Line-of-Sight communication. However, ITU-R[5] recommends considering rain attenuation in the design computation of radio links above 5GHz.Furthermore it becomes the dominant factor in path loss variation above 7 GHz and 10 GHz in tropical and temperate climates, respectively. Therefore, Line-of-Sight radio link designers should have a prediction method which predicts the impact of rain attenuation at higher frequencies so as to provide a reliable communication system at any environmental conditions.

The literature on rain fade above 10GHz is very rich. Since the tropical regions have high rainfall rate and rain intensity than other parts of the world, rain attenuation must be a model based on local rain data. Even if the ITU-R recommends[5] to use a local rain data for propagation modeling of tropical regions, much of the African continent including its equatorial and tropical area is still not investigated adequately in this context. However, there are few researches that have been carried out which model rain attenuation from data collected over the location from a different place in Nigeria [29], Sudan[30], and Ethiopia [31].

2.2.1 Rainfall Rate

Determination of rain fades basically depend on the rain rate R(mm/hr), raindrop size and shape, and volume density (number of drops per m3). Of these factors, only rain rate is readily measured unless a radar system is available; for this reason, rain rate is most often used parameter for rain fade characterization[27].

Rain attenuation can be predicted by collecting and analyzing data over a period of time[29, 32]. It is universally accepted that for accurate prediction of rainfall attenuation, rain data with lower sampling time is necessary. Therefore, recorded rainfall data at one minute or lower integration time can be applied for effective radio links design. Based on the recommendation of ITU-R[5], prediction of rain attenuation requires rainfall rate at an integration time of one minute. However, one-minute integration time rain data is rare in many regions of the world. This is the only reason that force the radio system engineers and designers to use a rain rate conversion method. This conversion method converts rainfall rate from the higher integration times available in the rainfall dataset to the ITU-R recommended one-minute integration time.

There are several methods of rainfall rate conversion developed by researchers. Some of the methods are dependent on regional factors. Some researchers divided rainfall rate conversion techniques into three: empirical, physical and analytical. ITU-R P 837.7[33]and Segal[34] employ an empirical conversion technique depending on the power-law relationship. This method was used by Ajayi and Ofoche [32] to convert rainfall rate in many locations of Nigeria. Afullo and Owolawi[29] developed rainfall rate contour maps for South Africa's locations for 5-minute to one-minute integration times. Fashuyi et al [35], using 60-minute and one-minute integration time for Durban, developed conversion factors that could be applied by other sites in South Africa to convert their 60-minute data to their equivalent one-minute data.Feyisa D. et al[36], proposed the rainfall rate conversion factors from 15-minute to 1-minute integration time; the development of rainfall rate and fade margin contour maps for Ethiopia sites. Fortunately, for this research works a rain rate of one-minute integration time is obtained from a rain rate measurement device installed at Jimma University, Ethiopia.

2.2.2 Rainfall rate distribution model

To determine the total path attenuation, the microwave path loss due to rain attenuations must be added with the free-space loss (FSL) while considering the anticipated rain rates. The rain rate is usually measured in millimeters per hour. According to, rain at a rate of 100 mm (4 inches) per hour or greater is considered as heavy rain. The rain rate is generally governed by the size and shape of the raindrops. The path loss normally varies with both the raindrop size distribution (RSD) and rain rate. In addition to this, the rain rate has a non-uniformity profile. Moreover, the size of the rain cell (area occupied by rain) considered as it is found in the path of the microwave link. The heavier the raindrops, the smaller will be the rain cells. Rainfall is a time-varying random process varying over different locations of the world[5]. The statistical distribution of rainfall rate is used to understand its effect on radio wave propagation. The important parameter for rain attenuation is $R_{0.01}$ obtained from the cumulative distribution of rainfall rate at 0.01%-time exceedance.

Many authors have conducted research on the prediction of rain fading, as detailed in [3, 5, 24, 36-38]. Most of these authors proposed models for the prediction of rain attenuation, particularly in circumstances where satisfactory measurements are unavailable. Due to the stochastic nature of rain process in time and space, it is challenging to get a model that adequately predicts the dynamic behavior of propagation in the rain. However, there is a requirement for accurate propagation estimation due to the fact that over-prediction results in costly over-design, whereas, under-prediction can result the unreliability of the systems.

Efforts have been made initially by the ITU-R 837[33] and then by Crane[37] to classify the world into rain climatic zones to expand the existing propagation data to a broader range. These models have however, resulted in much inaccuracy in tropical and equatorial regions because of the fact that most of the recorded dataset was developed for temperate zones[25].It observed that the current ITU-R rain attenuation estimation technique is not as precise for the tropical zone as it has been observed in the temperate zone.

According to ITU-R P 837[33] the world divided in to zones of global rainfall rate depending on experimental measurements from various areas of the world. It classifies the globe into 15 rainfall climate zones at different percentages of time exceedance. Accordingly, the important parameters for the determination of rainfall rate for the location under consideration at any percentage of exceedance are longitude and latitude. Using ITU-R P 837-1 recommendation, Ethiopia has four rainfall climate zones namely, C, D, E, and J. However, the ITU-R classifications are not necessarily sufficient designations[5]. From this work, the rainfall rate values at different percentages of time for different locations of Ethiopia do not correspond to

ITU-R classifications.

Crane [37] categorized the earth into eight zones, designated A to H with varying amounts of dryness to wetness. Label H is the tropical wet while A implies arctic dry. Using measured datasets, there were differences in rainfall rate at lower percentages of exceedance that leads to the formation of more designations. D zone was then classified into D1- D3, where D1 and D3 stand for driest and wettest seasons respectively. Additionally, this zone of rainfall rate world map gave further designations of B region such as B1 and B2. As a case in point, Feyisa, Afullo and Tunde [36] have conducted investigative studies on the analysis and modeling of rainfall and clear-air atmospheric parameters that contribute wireless network outage in the horn of Africa for the first time. Continuing from that, the current research proposed rain fade mitigation technique based on local rain data.

2.2.3 Rain attenuation models

In the planning of terrestrial Line-of Sight systems, a fairly precise rainfall-rate statistics data is essential for the proper prediction of rain-induced attenuation on propagation paths. A number of models have been proposed for the prediction of rain attenuation on terrestrial radio links. These models are intended for the estimation of rain attenuation in cases when adequate direct measurements are not available. Most of the methods proposed for predicting rain-induced attenuation make use of the long-term cumulative distribution of point rainfall measurement[40].

There are two broad sorts of rain attenuation predictions on any microwave link:

1. The analytical models which are based on physical laws governing electromagnetic wave propagation and which attempt to reproduce the actual physical behavior in the attenuation process;
2. The empirical models which are based on measurement databases from stations in different climatic zones within a given region.

Various rain attenuation estimation models are available depending on the climatic and geographical conditions. The important models are Crane global model, Two-component model, Simple Attenuation model, Garcia model, International Telecommunication Union Radio Communication sector (ITU-R) model, Bryant model and Moupfouma model.

Rain attenuation over a terrestrial path is defined as the product of specific attenuation (dB/km) and the effective propagation path length (km). The effective path length is determined from the knowledge of the link length and the horizontal distribution of the rain along the path. The rain attenuation A (dB) exceeded p % of the time is calculated as:

$$A = \Upsilon(R)d_{eff} = \Upsilon(R)dr \tag{2.1}$$

ITU-R P.838-3 [35] gives the method for the analyses of specific attenuation,$\Upsilon(R)$(dB/km), from the rain rate R (mm/hr) exceeded at P percent of the time, where the two quantities are related as,

$$\Upsilon(R) = KR^{\alpha} \tag{2.2}$$

where K and α rely on the frequency and polarization of the electromagnetic wave. These can be calculated by interpolation considering a logarithmic scale for k and linear for α. The frequency range is considered from 1 to 1,000 GHz. Similarly, the path reduction factor is r and d is the radio link path length in km for p time percentage.

A. ITU-R P.530-16 Model

The ITU-R P.530-17[5] gives a simple technique that may be used for estimating the long-term statistics of rain attenuation. The following simple procedure is presented in this model for estimating the long-term statistics of rain attenuation:

Step 1: - Rain rate R0.01 exceeded for 0.01% of the time (with an integration time of 1 min) is calculated.

Step 2:- Specific attenuation specified in equation (2.2), (dB/km) is computed for desired frequency, polarization and rain rate based on Recommendation ITU-R P.838-3[41].

Step 3: - Calculate the effective path length,d_{eff}, of the link by multiplying the actual path length d by a distance factor r. An estimate of this factor is given by:

$$r = \frac{1}{0.477d^{0.633}R_{0.01}^{0.073\alpha}f^{0.123} - 10.579(1 - \exp(-0.024d))} \tag{2.3}$$

where f (GHz) is the frequency and α is the exponent in the specific attenuation model from Step 2. The maximum recommended r is 2.5, so if the denominator of equation (3) is less than 0.4, use r = 2.5.

Step 4: - An estimate of the path attenuation exceeded for 0.01% of the time is given by:

$$A = \Upsilon(R)d_{eff} = \Upsilon(R)dr \tag{2.4}$$

Step 5: - The attenuation exceeded for other percentages of time p in the range 0.001% to 1% may be deduced from the following power law:

$$\frac{A_p}{A_{0.001}} = C_1 P^{-(C_2 + C_3 \log_{10} P)} \tag{2.5}$$

$$C_1 = (0.007^{C_0})[0.12^{1-C_0}] \tag{2.6}$$

$$C_2 = 0.855C_0 + 0.546(1-C_0) \tag{2.7}$$

$$C_3 = 0.139C_0 + 0.043(1-C_0) \tag{2.8}$$

$$C_0 = \{^{0.12+0.4[\log_{10}(\frac{f}{10})^{0.8}], f\leqslant 10GHz}_{0.12, f<10GHz} \tag{2.9}$$

Step 6: - If worst-month statistics are desired, calculate the annual time percentages p corresponding to the worst-month time percentages p$-w$ using climate information specified in Recommendation ITU-R P.841-5[42]. The values of A exceeded for percentages of the time p on an annual basis will be exceeded for the corresponding percentages of time p_w on a worst-month basis.

B. Moupfouma's Model

The space between the two ground stations, L, determines a terrestrial microwave link. As the first step, this model takes the rainfall rate value at 0.01% of the time for the determination of rain attenuation exceeded for the same percentage of time. The rain attenuation is defined as[21]:

$$A_{0.01} = KR_{0.01}^{\alpha} L_{eq}(R_{0.01}, L) \tag{2.10}$$

where$R_{0.01}$ and$A_{0.01}$ $A_{0.01}$ are the rainfall rate and path attenuation at 0.01% of time. Leq is the propagation path length given as:

$$L_{eq}(R_{0.01}, L) = L\exp(\frac{-R_{0.01}}{1+\zeta(L)R_{0.01}}) \tag{2.11}$$

where $\zeta(L) = -100$ for any $L \leqslant 7$ km; and $\zeta(L) = (44.2L)0.78$ for any$L < 7$km. Additionally, this model gives a method to determine the occurrence of attenuation due to rain on a given microwave link as:

$$P(A_{0.01}) \geqslant \alpha = 0.01(\frac{A_{0.01}}{\alpha+1})\phi(\alpha)\exp(9.21(1-(\frac{\alpha}{A_{0.01}}))\eta(\alpha)) \tag{2.12}$$

where$\phi(\alpha) = (\frac{\alpha}{A_{0.01}})\ln(\frac{\alpha}{A_{0.01}}+1)$

C. Crane Global Rain Attenuation Model

The Crane Global model[37] was developed for use on terrestrial paths. The model is based entirely on geophysical observations of the rain rate, the rain structure and the vertical variation of atmospheric temperature. The model was developed based on data analyzed for path lengths of 5, 10 and 22.5 km. To obtain a sufficient sample size at 22.5 km, Crane assumed that for point rates in excess of 25 mm/h, their occurrence probabilities were independent over distances greater than 10 km. This assumption was based upon experience with weather radar data. The assumption was also in an agreement between observations at path lengths of 10, 15, 20 and 22.5 km and with the power law approximation.

Crane accomplished this model by a piecewise representation of the path profile by exponential functions. An adequate model results when two exponential functions are used to span the 0–22.5 km distance range, one from 0 to$\delta(R)$ km and the other from $\delta(R)$ to 22.5 km. The resulting attenuation model for a given rain rate is given by:

$$A_T = \Upsilon(R)(\frac{\exp(y\delta(R))}{y})\frac{\exp(zD)-\exp(z\delta(R))}{y}\exp(\alpha\beta), \delta(R) < D < 22.5 \tag{2.13}$$

$$A_T(R,D) = \Upsilon(R)(\frac{exp\Upsilon y\delta(R)}{y}), 0 < D < \delta(R) \tag{2.14}$$

whereA_T is the horizontal path attenuation (dB), R the rain rate (mm/h), D the path length (km) and $\Upsilon(R)$ the specific attenuation. The remaining coefficients are empirical constants of the piecewise exponential model.

$$B = \ln(b) = 0.83 - 0.17\ln(R) \tag{2.15}$$

$$C = 0.26 - 0.03\ln(R) \tag{2.16}$$

$$\delta(R) = 3.8 - 0.6\ln(R) \tag{2.17}$$

$$U = \frac{B}{\delta(R)} + C \tag{2.18}$$

$$y = \delta(U) \tag{2.19}$$

$$z = \delta(C) \tag{2.20}$$

2.3 Rain Attenuation Mitigation Techniques

Some of the existing rain fades mitigation techniques are discussed below. Almost all fade mitigation techniques are reviewed [8, 18] for tropical regions. The key objective for implementing Fade Mitigation Technique (FMT) system should be the avoidance of static channel parameters and the design of adaptive systems that compensates for channel effects only when required, while at the same time providing the desired minimum QoS (quality of service) under clear-sky conditions. Fade Mitigation Technique (FMT) for the physical layer can be divided into[43]:

1. **Diversity:-** is the fade avoided by the use of another less impaired link
2. **Power Control:-** is to transmit power level fitted to propagation impairments.
3. **Adaptive waveform :-** is the process of fade compensated by a more effective modulation technique and coding scheme,

2.3.1 Diversity

The objective of these techniques is to re-route information in the network in order to avoid impairments due to an atmospheric perturbation. Here three types of diversity techniques can be considered: site (SD), satellite (SatD) and frequency (FD) diversity.

2.3.1.1 Frequency diversity (FD)

Frequency Diversity is a technique which is based on the fact that payloads using two different frequency bands are available onboard. When a fade is occurring, links are rerouted using the lowest frequency band payload, less sensitive to atmospheric propagation impairments. FD was employed in [8]. They used frequency domain separation (in closed loop control) of propagation factors based on the fact that lower frequency components of the attenuation power spectrum are associated with gaseous absorption, mid frequencies with clouds and rain, and higher frequencies with scintillations. This makes it possible to achieve the necessary separation through appropriate filtering.

2.3.1.2 Site Diversity (SD) FMT

It is based on the premise that the probability of attenuation being exceeded simultaneously at two sites is less than the probability of the same attenuation being exceeded at one of the sites by a factor which decreases with increasing distance between the sites and with increasing attenuation. Intense rain cells cause large attenuation values on an earth-space link and often have horizontal dimensions of no more than a few kilometers.

SD systems can re-route traffic to alternate earth stations with consequent considerable improvements in the system reliability. A balanced SD system (with attenuation thresholds on the two links equal) uses a prediction method that computes the joint probability of exceeding attenuation thresholds and is considered the most accurate and is preferred by ITU[13] .

SD is based on the change of the network routes; so, it applies only for the Fixed Satellite and terrestrial Service. SD takes advantage that two fades experienced by two Earth Stations separated by a distance (at least 10km) higher than the size of a convective rain cell and are statistically independent. The Earth station affected by a weaker event is used and the information is transmitted to the original destination through a separated terrestrial network.

2.3.1.3 Satellite Diversity (SatD)

Satellite Diversity is regarded in two different ways: on one hand, when designing the system, by optimizing the size of the constellation (that is the number of satellites) in order to prevent communications at low elevation angles. On the other hand, in allowing Earth Stations to choose between various satellites, the one for which the most favorable link with respect to the propagation conditions exists.

2.3.2 Power control (PC)

It is the process of varying transmits power on a satellite link, in the presence of path attenuation, to maintain a desired power level at the receiver. Power control attempts to restore the link by increasing the transmit power during a fade event, and then reducing power after the event is back to its non-fade value. There are four types of Power Control FMT concept: Up-Link Power

Control (ULPC), End-to-End Power Control (EEPC), Down-Link Power Control (DLPC) and On-Board Beam Shaping (OBBS).

2.3.3 Adaptive waveform

These FMTs could be split into three types. These types are Adaptive Coding (AC) technique, Adaptive Modulation (AM) technique and Data Rate Reduction (DRR) technique. The introduction of redundant bits to the information bits when a link is experiencing fading, allows detection and correction of the errors caused by propagation impairments and it leads to a reduction of the required energy per information bit. Adaptive coding technique consists in implementing a variable coding rate matched to impairments originating from propagation conditions.

2.3.3.1 Adaptive modulation

In adaptive modulation scheme, the constellation size is allowed to vary depending on the conditions of the wireless channel. Higher modulation orders are used to maximize the spectral efficiency during good channel condition. However, the higher modulation schemes such as 64QAM have higher BER that lower modulation order schemes such as 4QAM. When the channel condition is bad, a lower modulation order should be used to maintain the link availability.

2.3.3.2 Adaptive Coding and Modulation

It is an adaptive FMT type in which this thesis mainly focus on. Adaptive Coding and Modulation is a channel condition adaptation mechanism which combines the advantage of changing modulation order and coding rate. It dynamically tracks the channel conditions by estimating

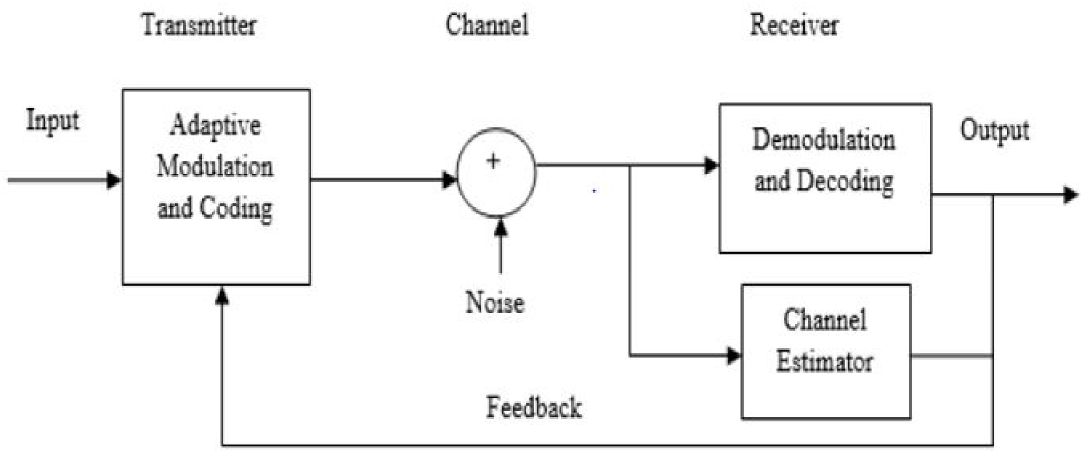

Figure 2.1: ACM system model.

the wireless channel at the receiver and then feeding back estimated data to the transmitter as shown in Figure 2.1. Based on the quality of the channel, the transmitter adapts its coding and modulation schemes to improve throughput and maintain link availability.

2.3.4 Adaptive Techniques

The basic principle that govern adaptive transmission is to secure a constant E_b/N_0 by varying the transmission parameter such as, power level, symbol rate, modulation order, coding rate/scheme, or any combination of these parameters. Thus, without increasing probability of error(BER) these schemes offer high average spectral efficiency by transmitting at high speeds under favorable channel conditions, and reducing throughput as the channel degrades[46].

There are several practical constraints which determine when adaptive coding and modulation should be used. If the channel is changing faster than it can be estimated and fed back to the transmitter, adaptive techniques will perform poorly, and other means of mitigating the effects of fading should be used.In our case we have assumed that there is a perfect knowledge of channel at the receiver.This assumption makes that the fed backing system is instantaneous and delay free.

In addition to this ,since the transmitter and receiver knows the channel gain we compensate deep fades by changing the coding rate so that the BER remains small.Hence, burst errors will not typically occur due to deep fading.Thus, channel interleaving is not required.

To efficiently exploit the time-varying fading channel, the proposed mitigation technique transmitter should adjust its modulation and coding rate (defining the so-called Adaptive Coded Modulation) on the basis of the channel state information (CSI), i.e., the set of parameters characterizing well the quality of the transmission. The main issue in such adaptive coding and modulation (ACM) schemes is to translate the CSI into a transmission performance metric. Commonly, the transmitter chooses the modulation and coding scheme (MCS) depending on the signal to noise ratio (SNR), which defines the performance measured by the bit error rates (BER).

ACM is one of the various techniques that the satellite industry is utilizing to help reduce bandwidth costs for customers and improve network performance. It may be a solution that can provide advantages for your network implementation, or it may have limitations given hardware costs at each site and other factors[44].

S. S. Das et al [18], have made a mitigation technique comparison for Ka-band satellite links.In this research work, methods to implement FMT through AMC described. From their comparison, it is known that all other mitigation schemes require data samples at the base-band(I/Q), whereas AMC operates on bits at the receiver which are generated at the output of the forward error control decoder (i.e. the AMC is controlled from the application layer).

In another research work L.Castanet et al [45], adaptive modulation/coding described as of high interest as they allow the performance of individual links to be optimized, and the transmission characteristics to be adapted to the propagation channel conditions and to the service requirements for the given link. Those techniques are expected to be promising in particular in point-to-point service scenario.

2.3.5 Non-adaptive Techniques

In a communication environment where the estimated SNR is sufficiently high and constant, the general strategy to improve spectral efficiency is to employ fixed transmission mechanism. These non-adaptive mechanisms are developed for worst-case transmission medium situation. They need a fixed link margin to maintain the target BERB performance when the channel quality is poor. Thus, these systems are effectively designed for the worst-case channel conditions, resulting in insufficient utilization of the full channel capacity[46].

In a fixed modulation scheme, a single modulation scheme is used to enhance data rate. In addition, by employing forward error correcting (FEC) codes, the amount of error that may be introduced in the wireless system can be minimized. For a fixed modulation and coding, a single code rate and modulation order pair such as 64QAM and 2/3 Rc is employed. However, SNR cannot be kept constant for the whole duration of transmission as the wireless medium by itself is varying with time. These dynamically varying of SNR may lower the performance of wireless communication. Hence, fixed techniques are usually employed to improve either the throughput or BER.

Sriram Vishwanath and Andrea Goldsmith[48] indicates that by assuming instantaneous and error-free channel gain and phase knowledge at the transmitter and the receiver, it is possible to determine the optimal adaptation strategy that maximizes the throughput of this system, while achieving a given bit-error rate under an average power constraint.

In comparison to communication systems designed using fixed coding, ACM can increase the throughput of a robust link by allowing it to dynamically adjust to a less robust modulation/-coding resulting in a higher throughput under clear sky conditions. Conversely, when compared to a modestly robust fixed rate coded link, ACM can provide increased link availability by dynamically adjusting to lower order MODCOD under rain fade conditions. Utilization of ACM considerably improve link throughput and/or link availability when compared to a fixed adaptation system service.

Researchers have studied the use of Adaptive coding and Modulation (ACM) for satellite Line-of-Sight communication to mitigate rain fades[15, 49]. I. Abubakar et al [15] studied the implementation of adaptive modulation and coding (ACM) for the real operating satellite-based internet protocol (IP) communication system from the Nigeria communication satellite (NigComSat-1R) very small aperture terminal (VSAT) network. In this research work, different modulation schemes are chosen according to the weather conditions in order to achieve the highest available data rate and preserve the link availability. The results of the experiment they had conducted indicated that at least a 24% bandwidth reduction can be achieved with the same data rate by implementing the ACM technique.

J. Petranovich [17] proposed ACM as a powerful tool for mitigating the large weather induced fades experienced in Ka-band. A sufficiently large set of MODCOD points can accommodate very deep fades.

Telsat [44] has extensive experience designing, and operating ACM systems at both Ku-band and Ka-band and proved that ACM can significantly increase link throughput and/or link availability when compared to a fixed MODCOD service.

Sami H. O. Salih and Mamoun M. A. Suliman [50] implement an Adaptive Modulation and Coding (AMC) features of the WiMAX and LTE access layer using Software Defined Radio (SDR) technologies in MATLAB. Even though this paper mainly focuses on the physical layer design (i.e. Modulation), it emphasized the requirement of better SNRs to overcome any Intersymbol Interference (ISI) and maintain certain bit error ratio (BER) when modulation technique such as 64- QAM with fewer overhead bits are used.

E. Alberty et al. [51] numerically showed that adaptive coding and modulation techniques could significantly increase the average system throughput and availability, thus making the system economically more attractive for DVB-S2 interactive applications.

G. Albertazzi et al. [52] has simulated WCDMA turbo code with several coding rates and modulation formats in a satellite environment with flat and time selective Ricean fading channel and in the presence of strong non-linear distortion. The conclusion drawn in this paper showed that increasing the coding rates or the modulation order the packet Error Rate(PER) performance decreases with respect to the AWGN channel condition, but is never dramatic.

Andrea J. Goldsmith and Soon-Ghee Chua[10] apply coset codes to adaptive modulation in fading channels to improve the energy efficiency and increase the data rate over a fading channel. Assuming flat-fade channel they have showed an effective coding gain of 3 dB relative to uncoded adaptive MQAM for a simple four-state trellis code, and an effective 3.6-dB coding gain for an eight-state trellis code.

Andrea J. Goldsmith, and Soon-Ghee Chua [53] has proposed a variable-rate variable-power M-ary quadrature amplitude modulation (MQAM) scheme to mitigate fading channels.This scheme has shown to exhibit a 20-dB power gain over non adaptive modulation on a flat Rayleigh fading channel. This scheme did not consider coding, and this resulted in an 11-dB gap from the Shannon capacity of the Rayleigh fading channel with transmitter and receiver side information. Trellis codes can be superimposed on the adaptive modulation for a coding gain of around 5 dB [47], but the resulting scheme is still more than 6 dB away from capacity.

To summarize the fade mitigation techniques , the power control technique requires high power capacity if the rain fade lasts long. Diversity techniques are also very expensive because of associated equipment have to be redundant. Due to its high-cost diversity techniques are less attractive to network operators. Even though any conventional technique for rain fade mitigation is not fully efficient, Adaptive Coding and Modulation scheme is preferable than others for mitigating rain fade in terrestrial Line-of-Sight microwave and millimetric band links.

2.4 Performance Analysis of Adaptive Coding and Modulation Schemes

2.4.1 SNR estimation

For an additive white Gaussian noise (AWGN) channel model, a randomly generated noise is added to the transmitted signal before its reception. In any communication system, the noise power should not be excessively large compared to the signal power in order to have a good quality of service signal reception. The signal-to-noise ratio is defined as the ratio of signal power Pr to noise power Pn within the spectrum/bandwidth of transmitted signal (2B) and noise power spectral density of No/2. The SNR in dB is given by:

$$SNR(dB) = 10\log_{10}(\frac{P_r}{P_n}) \tag{2.21}$$

It can also be expressed as

$$SNR = \frac{P_r}{BN_o} \tag{2.22}$$

2.4.2 Channel model

To examine the performance of any communication system, a precise description of the wireless channel is vital to address the environment in which the transmission is made. Practical assumption for a fixed, LOS wireless channel is the additive white Gaussian noise (AWGN) channel [54] which is flat and not “frequency-selective” as in the case of the fading channel.

Rayleigh fading channel is modeled by several multipath components having comparatively similar signal level, and uniformly dispersed phase, which implies there is no Line-of-Sight (LOS) route between sending and receiving end.Another most frequently employed fading channel model, which is called the Rician fading model, is adopted when there is a dominant LOS path and a number of weak multipath components in the propagation environment. These two fading models are mostly applicable for modeling mobile communication [55] which is not the communication link this research work based on.

Furthermore, this research work showed that the performance of AWGN channel is the best of all channels as it has the lowest bit error rate (BER) under QAM, 16-QAM and 64-QAM modulation schemes. Consequently, this research work exploits additive white Gaussian noise (AWGN) as a channel model. The flat fading assumption of in our model implies that the channel coherence bandwidth is greater than the signal bandwidth

2.4.2.1 AWGN

The additive white Gaussian noise (AWGN) channel model is a channel whose sole effect is the addition of a white Gaussian noise process to the transmitted signal. The term “additive” means that the noise is simply superimposed or added to the transmitted signal, that there are no multiplicative mechanisms at work. Since white light contains an equal amount of all frequencies within the visible and electromagnetic radiation, it is used here to depict that the noise in AWGN channel has the same power spectral density for all frequencies of interest in the communication system. The term ”Gaussian” describes that each transmitted symbol through the AWGN channel is independently affected by noise as a Gaussian process is known to be uncorrelated[56]. This channel is mathematically described by the relation

$$r(t) = s(t) + n(t) \tag{2.23}$$

where $r(t)$ is the received signal,$s(t)$ is the transmitted signal and$n(t)$ is the sample of AWGN added at the channel with a known power spectral density. In practice, modeling of AWGN channel includes calculating the noise power from a given SNR and known signal power. The message signal is then superimposed with a zero mean and unit variance noise before transmission.

2.4.3 Channel coding

The channel coding (also called error correction) is a way of improving the BER performance in digital communication systems especially when the power of the system is fixed and limited. In forward error correction (FEC)channel coding, redundant bits are added to the transmitted signal at the transmitter [1, 57]. This redundant data allows the receiver to detect and correct a limited number of errors experienced by the wireless channel throughout the transmission. The most commonly used FEC is a convolutional coding scheme. With proper channel coding and decoding techniques, information can be transmitted with a rate near the Shannon capacity but with a small probability of error. The channel coding consists of channel encoder at the transmitter part and decoder at the receiver side.

2.4.3.1 Convolutional encoder

"Convolutional codes, invented in 1954 by P. Elias, constitute a family of error correcting codes whose decoding simplicity and good performances, in particular for the Gaussian channel, are, without doubt, very much at the origin of their success”[58].

The channel encoder contains finite-state shift registers which are used to temporarily store and operate shifting of input bits and exclusive-OR logic circuits that generate the encoded output. In general, the registers consist of K (each with k-bit input) stages and n linear function generators [54]as shown in Figure 2.2 below.

Convolutional codes are commonly described using two parameters: the code rate and

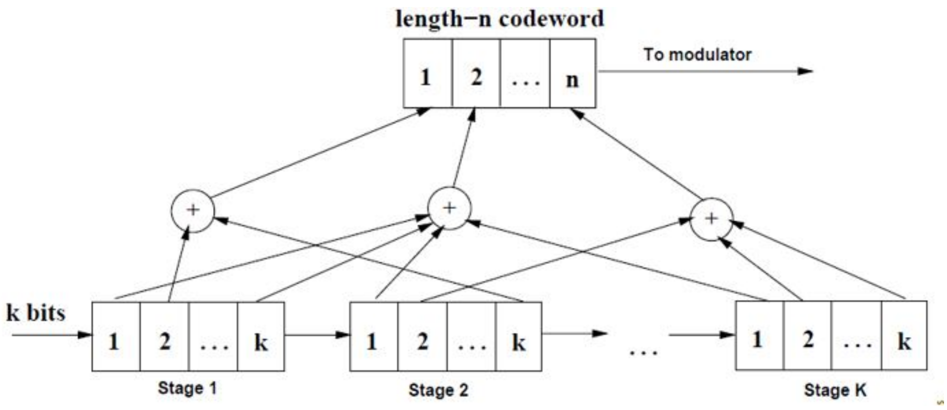

Figure 2.2: Convolutional Encoder[47]

the constraint length. The code rate,k/n, is expressed as a ratio of the number of bits into the convolutional encoder (k) to the number of channel symbols output by the convolutional encoder (n) in a given encoder cycle. Closely related to K is the parameter m, which indicates how many encoders cycles an input bit is retained and used for encoding after it first appears at the input to the convolutional encoder. The m parameter can be thought of as the memory length of the encoder.

The most widely exploited channel codes in real communication systems for the purpose of error correction are convolutional encoder. Convolutional encoder encodes the bit based on the current k input bits and few past temporarily stored inputs. A convolutional channel encoder is specified by three integers n, k, K or (k/n, K) elements. A channel encoder with input k bits and output n bits is said to have a rate of k/n. The k/n ratio refers to the coding rate (Rc) of the system and K is the constraint length of the encoder. The parameter K, which is the constraint length, designates the" length" of the convolutional encoder. That means it signifies the number of k-bit stages that are available to provide the combinational logic that results the output symbol. The range of code rate is between 0 and 1.

The data rate can be increased by using a higher coding rate, but it reduces the BER. For example, an encoder with three bits of output for every single bit input, i.e. for k=1 and n=3, is expressed as a code rate of 1/3 as shown in Figure 2.3.

2.4.3.2 Viterbi decoding

The Viterbi decoding algorithm is commonly applied in decoding the convolutionally encoded data at the receiver side. It uses maximum-likelihood decoding technique in order to recover the transmitted bits by a trellis diagram. The decoded information is recovered with either a

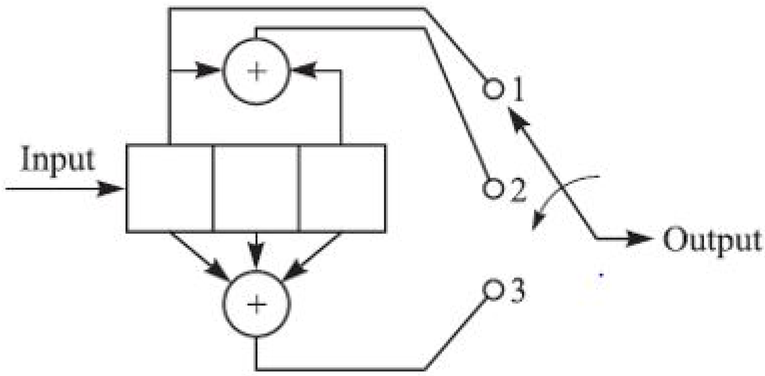

Figure 2.3: K=3, k=1 and n=3 convolutional encoder[54]

hard decision or a soft decision. Hard and soft decisions decoding techniques depend on the quantization type employed at the receiver.

- **Hard decision decoding (HDD): -**The received channel symbols are quantized to a single bit of precision. In HDD each coded bit is demodulated as 0 or 1.i.e the demodulator detects each coded bit(symbol) individually.HDD typically uses minimum decoding.
- **Soft decision decoding (SDD): -** uses multi-bit quantization (e.g. 3 bits/sample) on the received sample values. At least a two bits precision quantization is carried out in this type decoding. It performs better than a hard decision.In general the performance of SDD is about 2 dB better than HDD.

2.4.4 Modulation type

Modulation is a process of embedding the information message on to a carrier signal by changing its carrier phase, frequency or amplitude or combination of these. The commonly used modulation techniques are Phase Shift Keying (such as BPSK and QPSK) and M-ary Quadrature Amplitude Modulation (such as 8QAM and 256QAM) [47]. Multilevel or multiphase modulation (PAM, PSK, DPSK, or QAM) are bandwidth-efficient modulation schemes which allow us to achieve an R/W>1.

The choice of modulation scheme mainly relies on the channel characteristics. If the amplitude of the received signal is varied rapidly, QAM and PAM may be particularly vulnerable, because a wideband automatic gain control (AGC) must be employed to reimburse for the channel variations. In such a case, PSK or DPSK is more suitable, since the information is conveyed by the signal phase and not by the signal amplitude[54]. However, in MQAM the information bits are encoded in both the amplitude and phase of the transmitted signal. Thus, whereas both MPAM and MPSK have one degree of freedom in which to encode the information bits (amplitude or phase), MQAM has two degrees of freedom. As a result, MQAM is more spectrally efficient than MPAM and MPSK, in that it can encode the greatest number of bits per symbol for given average energy[47].

2.4.5 Bit error rate (BER) performance

In a wireless communication, the transmitted signal may be affected by noise, interference, distortion and multipath fading resulting in undesirable errors at the receiver end. Bit error rate is a crucial digital communication parameter which is employed to evaluate the performance of data transmission. Numerically it can be defined as the total number of bits received in error by the total number of bits that have been transmitted[59]. That is :

$$BER = \frac{Number\ of\ bits\ received\ as\ error}{Total\ number\ of\ transmitted\ bits} \tag{2.24}$$

The bit error rate can be enhanced by increasing the transmit power, choosing a desired modulation order and by channel encoding schemes[47] . The BER is the rate of error that occurs during transmission of information bits. Assuming perfect coherent receiver detection and square signal constellation with size of M, the probability of bit error for M-ary QAM modulation scheme under AWGN channel is expressed as [47]:

$$BER = \alpha Q(\sqrt{\beta SNR}) \tag{2.25}$$

Where$Q(z)$ is complementary error function,α andβ are constants expressed as

$$\alpha = 4\frac{\sqrt{M}-1}{\sqrt{M}\log_2 M}, \qquad \beta = \frac{3\log_2 M}{(M-1)} \tag{2.26}$$

SNR is taken as the average received signal-to-noise ratio. The Q function refers to the probability that a Gaussian variable x with zero mean and unit variance is more than z. It is given by [47]:

$$Q(z) = P(x > z) = \int_z^{\infty} (\frac{1}{2\pi}) \exp(-x^{\frac{1}{2}}) dx, x > 0 \tag{2.27}$$

For rectangular MQAM and nonrectangular MQAM BER is defined by [47]

$$P_b \approx 2\frac{(\sqrt{M}-1)}{\sqrt{M}\log_2 M}Q(\sqrt{SNR\frac{\log_2 M}{(M-1)}}) \tag{2.28}$$

$$P_b \approx \frac{4}{\log_2 M}Q(\sqrt{3\overline{SNR}\log_2 M}(M-1)) \tag{2.29}$$

2.4.6 Capacity in AWGN channel

An additive white Gaussian noise channel mathematically defined as:$y[i] = x[i] + n[i]$, where$x[i]$ is input signal to the channel, $n[i]$ is an AWGN random process and $y[i]$ is the channel output at discrete time i. For a fixed transmission technique, the spectral efficiency is the maximum limit of information bits a wireless channel can support per second per unit bandwidth. For a channel having bandwidth B, transmit power S, its SNR, the power in $x(i)$ divided by the power in $y(i)$, is constant and given by SNR=S/NoB. The capacity of this channel is given by Shannon formula[47]:

$$C = B\log_2(1+SNR) \tag{2.30}$$

Shannon's encoding illustrated that a data rate just about the capacity with small probability of error can be attained by utilizing encoding.

2.5 Soft computing Techniques for Adaptive Modulation and Coding Schemes

It is known that the wireless channel is complex and involve an indeterministic variation of the metrological and atmospheric environment. Due to this uncertain propagation path condition, it is difficult to adapt using the traditional hard computing techniques. The soft computing methods, do not require mathematical models, unlike the conventional techniques. Because of its ability to model systems with uncertainty and incompleteness, soft computing has a better advantage over conventional adaptive and non-adaptive technique in modeling time-varying wireless channel. Among several soft computing methods, fuzzy logic, neural network and neuro-fuzzy systems are most commonly used. Detail review of Neuro-Fuzzy based system, and related works of these techniques are presented in this section.

2.5.1 Fuzzy Logic System

Fuzzy set theory, which was initially invented by Lofti Zahed of the University of California at Berkeley in 1965, is a powerful tool to deal with the imprecision characteristics in decision-making problems involving uncertainty and vagueness of real-world applications[60]. This invention was not well recognized until Dr. E. H. Mamdani[61] who is a professor at London University, applied the fuzzy logic in a practical application to control an automatic steam engine in, which is almost a decade after the fuzzy theory was invented.

The fuzzy logic idea is similar to the human's feeling and inference process, unlike classical control strategy. The classical control method is a point-to-point control, whereas fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is stemmed from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships, which can be considered as a range of inputs.

The fuzzy logic inference system (FIS) performs arithmetic computation utilizing membership functions for modeling of fuzzy set linguistic variables. The fuzzy logic is useful for imprecise, uncertain information and complex-ill based systems. It also incorporates human experience based on if-then fuzzy rules in decision-making. It implements nonlinear systems using linguistic variables in a straightforward when adequate knowledge about the system is available.

2.5.1.1 Fuzzy inference system structure

Fuzzy inference systems are also known with other several names: It might be named as fuzzy-rule-based systems (FRBS), fuzzy models, fuzzy associative memories (FAM), or fuzzy controllers when used as controllers. The fundamental FIS architecture is shown in Figure 2.4 below[12]. Basically, it contains five components that are used to implement a fuzzy algorithm and resolve all of the associated ambiguity. These are:

i)Fuzzification: - The objective of the fuzzification is, to pick membership function, to convert the input from a crisp (real- value) into a set of fuzzy variables. The input is constantly a crisp numerical value restricted to the universe of discourse of the input variable and output is a fuzzy degree of membership in the qualifying linguistic set (always the interval 0 and 1).

It uses membership functions such as trapezoidal, bell or gaussian shapes for the conversion process.

ii) Rule-Based Reasoning: - Fuzzy rule-based systems (FRBS) use linguistic variables to justify via a sequence of logical rules that contain IF-THEN rules which create a link between antecedent(s) and consequent(s), respectively. An antecedent is a fuzzy clause with a certain degree of membership (between 0 and 1). Several antecedents might be connected with AND or OR logical operators in FRBS, where all parts are considered simultaneously and resolved into a single number. Consequents can also be embraced by numerous components, which are then combined into a single output of a fuzzy set [62].

Manipulating a fuzzy rule-based system involves the derivation of the desired "If-Then" fuzzy rules, dividing of universes, and addressing of the membership functions. Fuzzy rules can be easily and directly formulated by experts in the form of linguistic rules.

iii) Fuzzy set database: - that defines the fuzzy set membership functions used in fuzzy rules;

iv) Inference engine: - It is reasoning mechanism which performs the inference procedure based on the rules to draw output or conclusion;

v) Defuzzification: - It is an interface which translates back the fuzzy sets to crisp output using the center of gravity, mean of maximum or bisector area.

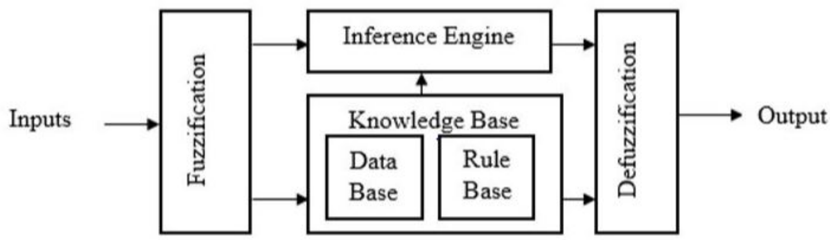

Figure 2.4: Structure of fuzzy logic system

2.5.1.2 Types of Fuzzy inference system

The most commonly used types of fuzzy system are three, namely[63]:

i) Mamdani fuzzy system: - the outputs of this model are fuzzy sets.

ii) Singleton fuzzy system: - the complexity of defuzzification of a linguistic variable may be simplified by using singleton membership function to the output parameter.

iii) Takagi-Sugeno (TKS) fuzzy system: - the output of this TKS model is a linear function of the input variables plus a constant term.

Their difference emanates from the specification of their consequent part (monotonically non-decreasing or bell-shaped membership functions, or crisp function) and thus the defuzzification schemes (weighted average, the centroid of area, etc.) are distinct as well [12]. For example, the most fundamental difference between Mamdani-type FIS and Sugeno-type FIS is the way the crisp output is generated from the fuzzy inputs. While Mamdani-type FIS uses the technique of defuzzification of a fuzzy output, Sugeno-type FIS uses a weighted average to compute the crisp output. The expressive power and interpretability of Mamdani output are lost in the Sugeno FIS since the consequents of the rules are not fuzzy [64]. But Sugeno has better processing time since the weighted average replaces the time-consuming defuzzification process. Due to the interpretable and intuitive nature of the rule base, Mamdani-type FIS is widely used in particular for decision support application.

Other differences are that Mamdani FIS has output membership functions whereas Sugeno FIS has no output membership functions. Mamdani FIS is less flexible in system design in comparison to Sugeno FIS as the latter can be integrated with ANFIS tool to optimize the outputs[64].

A comparison of Mamdani and S fuzzy inference type for air conditioning system is done in [64]. Among these two types of Fuzzy inference systems, Mamdani method is popular for capturing expert knowledge. It allows us to describe the expertise in a more intuitive, more human-like manner. However, Mamdani-type FIS entails a substantial computational burden. In contrast, the Sugeno method is more efficient computationally and works well with optimization and adaptive techniques, which makes it very attractive in control problems, particularly for dynamic non-linear systems. These adaptive techniques can be used to customize the membership functions so that the fuzzy system best models the data.

2.5.1.3 Membership function (MF)

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The membership function can be also expressed as a graphical representation of the contribution of each input. The input space is sometimes referred to as the universe of discourse. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system[61].

For any set X, a membership function on X is any function from X to the real unit interval [0, 1]. The membership function which represents a fuzzy set is usually denoted byμ_A. For an element x of X, the value $\mu_A(x)$ is called the membership degree of x in the fuzzy set. The membership degree$\mu_A(x)$ quantifies the grade of membership of the element x to the fuzzy set. The value 0 means that x is not a member of the fuzzy set; the value 1means that x is fully a member of the fuzzy set. The values between 0 and 1 characterize fuzzy members, which belong to the fuzzy set only partially. A fuzzy set is completely characterized by its membership function (MF). Since most fuzzy sets in use have a universe of discourse X consisting of the real line R, it would be impractical to list all the pair defining a membership function[61].

The simplest membership functions are formed using straight lines. Due to their simple formulas and computational efficiency, both triangular MFs and trapezoidal MFs have been used extensively, especially in real-time implementations. However, since the MFs are composed of straight-line segments, they are not smooth at the corner points specified by the parameters. [4, 5].

The most common types of MF are:

i) Triangular MFs

ii) Gaussian MFs

iii) π-Shaped Membership Function

iv) Trapezoidal MFs

v) Generalized Membership Function

vi) S-Shaped Membership Function

Since the development of a fuzzy logic concept, it has been used for modeling and making decisions in various wireless communication systems. A wide range of solutions has been developed concerning the problem of choosing the proper transmission parameters such as coding rate and modulation scheme for OFDM wireless communication systems based on the quality of the channel using fuzzy logic approach[65].

An adaptive coding and modulation scheme is proposed[66] using Fuzzy Rule Base System, where product codes are utilized with Quadrature Amplitude Modulation (QAM). In this research work, product codes and fuzzy rule base system (FRBS) has been utilized to enhance attainable throughput in an OFDM system with a fixed target BER and fixed transmit power for each subcarrier.

2.6 Neural Network Based Algorithms

An artificial neural network (ANN) is an intelligent system developed for the purpose of information processing, which mimics the biological neural systems. The ANN is usually used to process information, which is non-linear, complex and incomplete. It imitates the human brain with neurons which are interconnected by weights. This kind of neural network, has enormous skill for learning, optimization abilities and adapt themselves to respond to the continuously varying environment by adjusting the weights between the layers[63].

Radial basis function neural network (RBFNN), Multi-layer perceptron (MLP) network and neuro-fuzzy network are the most common architectures of neural networks. RBFNN is a multilayer feedforward network that consists of three interconnected layers: an input layer, hidden layer as well as output layer. In RBFNN, radial basis functions are used as activation functions for each hidden layer of the neural network. The output of the RBFNN is the weighted linear superposition of the radial basis functions.

RBFNN based adaptive modulation in OFDM systems has proposed in[67] to learn the features of M-QAM before recovering the original signal under a noisy environment. Adaptive resource allocation for OFDM systems using fuzzy and neural networks were proposed by[68]. The transmission parameters such as coding rate, power and modulation scheme are adapted based on the time-varying channel conditions in order to maximize the data rate and reduce BER.

2.6.1 Neuro-Fuzzy Approach

Neuro-fuzzy system is an artificial intelligence system that combines both fuzzy logic and neural networks. It takes advantage of fuzzy logic systems (e.g. if-then rules and ease of incorporating expert human knowledge available in linguistic forms) and neural networks (e.g. learning capabilities, optimization abilities). Fuzzy logic require adequate prior human knowledge to be initialized whereas neural network doesn't require any prior knowledge to be initialized. It only needs the fuzzy inference rules and parameter membership functions to be adjusted. As a result, Neuro-Fuzzy is efficient compared to fuzzy logic and neural networks[69].

In a fuzzy based system, the fuzzy rules and membership functions are obtained by trial and error; this makes the design of fuzzy systems a time-consuming task. The hybrid system uses the backpropagation learning technique of neural networks to train and automatically update membership functions. It improves the predictive capability of a system working in uncertain, imprecise and noisy environments.

2.6.1.1 Adaptive Network based Fuzzy Inference System

A special neuro-fuzzy method termed Adaptive Network-based Fuzzy Inference System (ANFIS) [12] is used as the model in our proposed algorithm. The ANFIS comprises the fuzzy logic component as well as the neural networks. The fuzzy logic system considers the imprecision and uncertainty of a system while neural networks takes the adaptability and learning capability of the system.

2.6.1.2 Neuro-fuzzy (ANFIS) structure

The ANFIS structure illustrated in Figure 2.5 is based on type 3 fuzzy inference system. Takagi and Sugeno's (TKS) rule-based fuzzy if-then rules are used in type-3 FIS. For simplicity, considering x and y as inputs and z as an output, the TKS rule is given by:

$$If\ x\ is\ A\ and\ y\ is\ B\ then\quad z = f(x,y) \tag{2.31}$$

where A and B are fuzzy sets and $f(x,y)$ is a crisp function. The function $f(x,y)$ is a polynomial of the input antecedent variables x and y. In this system, the output for each rule is obtained by

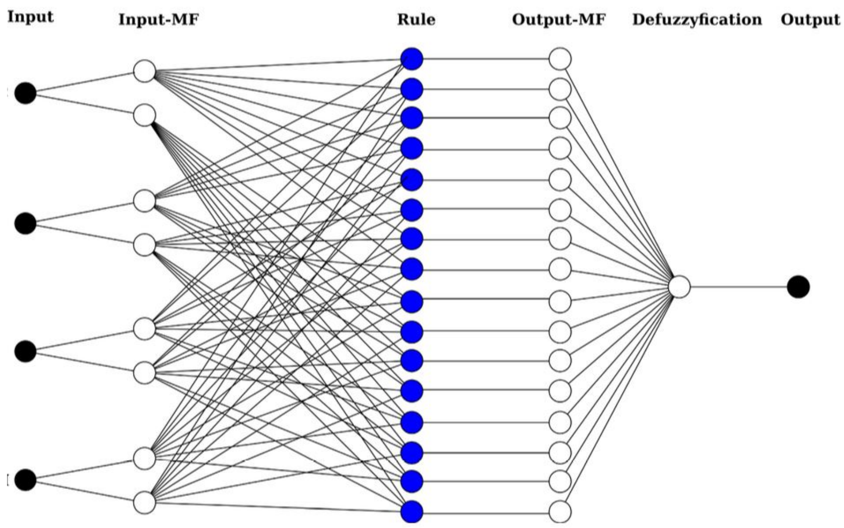

Figure 2.5: Type-3 ANFIS structure

adding a constant value to the linear combination of the input variables. The final result is then obtained by computing the weighted average of each rule's output.

Usually f(x, y) is assumed to be a first-degree polynomial then a linear Sugeno fuzzy model is formed. For this case, with two rules it can be expressed as:

$$Rule_1 = if\ x\ is\ A_1\ and\ y\ is\ B_1\ then f_1 = p_1x + q_1y + r_1 \tag{2.32}$$

$$Rule_2 = if\ x\ is\ A_2\ and\ y\ is\ B_2\ then\ f_2 = p_2x + q_2y + r_2 \tag{2.33}$$

where x and y are input parameters, A_1, A_2, B_1,andB_2 are membership functions, f_1 and f_2 are output linear functions, and p_1, p_2, q_1, q_2, r_1,andr_2 are the consequent parameter set determined during training of the neuro-fuzzy system.

The ANFIS structure consists of five layers corresponding to various functions. Each layer of the Type-3 ANFIS structure is presented as follows[12]:

Layer 1:- Every node in the first layer is an adaptive node with a function given as:

$$O_i^1 = \mu_(A_i)(x) \tag{2.34}$$

whereO_i^1 is the output of the i^{th} node in the first layer, x is input to the node i, A_i is the linguistic variable associated with the bell-shaped node function and μ_{A_i} is the grade membership function of A_i and is given by:

$$O_i^1 = \mu_(A_i)(x) = \frac{1}{1 + (\frac{x - C_j}{a_j})^{2b_j}} \tag{2.35}$$

where a_i , b_i , c_i is the premise parameters set that define membership functions.

Layer 2:- Each node in this layer is a fixed circle node labeled by π and determines the firing strength of a rule by multiplying the incoming signals (membership functions). The firing strength of each fuzzy rule for this layer is given by:

$$O_i^2 = w_i = \mu_{A_i}(x)\mu_{b_i}(x) \tag{2.36}$$

Layer 3: - This layer is a fixed node used to compute the ratio of the i^{th} rule's firing strength to the total of the firing strengths, which is normalized value and is given by:

$$O_i^3 = \overline{w_i} = \frac{w_i}{w_1 + w_2} \tag{2.37}$$

Layer 4: - Each node in this hidden layer is an adaptive node with a function given by:

$$O_i^4 = \overline{w_i} f_1 = \overline{w_i}(p_1 x + q_1 y + r_1), i = 1, 2, ... \tag{2.38}$$

where $\overline{w_i}$ is the output of the layer 3 and p_i , q_i , r_i is the consequent parameter set.

Layer 5: - This is the output layer with a circle node labeled by$\sum$ and determines the overall output by summing all the incoming signals, i.e.

$$O_i^5 = \sum_i \overline{w_i} f_i \tag{2.39}$$

The output of the neuro-fuzzy system is expressed as:

$$O_i^5 = \frac{\sum_i \mu_{A_i}(x) f_i}{\sum_i \mu_{A_i}(x)} \tag{2.40}$$

2.6.1.3 Hybrid learning algorithm

Finding the best values of the equivalent fuzzy inference system parameters by applying a learning algorithm is the key objective of the ANFIS. The parameter optimization is done in such a way during the training session that the error between the target and the actual output is minimized. A hybrid algorithm is used for optimization, which is the combination of least square estimate and gradient descent method. The parameters to be optimized in ANFIS are the premise parameters. These parameters define the shape of the membership functions. Thus, to train the ANFIS, a hybrid learning technique is utilized [60].

During the forward pass, each node output goes forward until the last layer and the design parameters are determined by the least square method. In the backward pass, the error signals propagate to the backward to update the premise parameters/membership functions by gradient descent technique. Thus, the least squares method and gradient descent technique are used to optimize design parameters and update the membership functions respectively. The output in

Figure 2.5 can be expressed as:

$$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2 \tag{2.41}$$

$$f = \overline{w_i} f_1 + \overline{w_i} f_2 \tag{2.42}$$

$$f = (\overline{w_1} x) p_1 + (\overline{w_1} y) q_1 + (\overline{w_1}) r_1 + (\overline{w_2} x) p_2 + (\overline{w_2} y) q_2 + (\overline{w_2}) r_2 \tag{2.43}$$

where f is the linear output function and p_1,p_2,q_1,q_2,r_1,and r_2 are the design parameters set determined during the ANFIS training.

N. Walia et al [60]has made a survey on adaptive Neuro-Fuzzy inference system. In this work, a hybrid algorithm is applied and showed that ANFIS can enhance the quality of generated relevant fuzzy if-then rules obtained from human experts to describe the input-output behavior of a complex system.

Nnebedum V.I and Onyedumekwu N. G [70] has carried out a research that focuses on how to simulate Adaptive Modulation to maintain steady low bit error rate, using MATLAB and Fuzzy Interface System. In this research work it is demonstrated that as the distance between the transmitting base station and the mobile receiver increases, the SNR decreases and the order of Quadrature Amplitude Modulation (QAM) selected decreases, to ensure a stabilized bit error rate. Whereas, as the mobile user comes nearer the transmitting base station, the order of QAM increases to ensure maximum use of available bandwidth for increased throughput and also stabilized bit error rate.

K.Seshadri Sastry [71] propose an adaptive modulated OFDM system using neuro-fuzzy controller to improve system performance of an OFDM. The proposed system has been simulated in MATLAB and compared with existing systems. The comparison result showed that the proposed technique outperforms fixed modulation system, and better than fuzzy based adaptive modulator.

I. Adegbindin et al [72] has proposed mitigation of propagation impairment at SHF and EHF satellite network in tropical climate using intelligent weather awareness technique. In this research work, Rain Induced Attenuation (RIA) has been estimated for three locations based on suitable for tropical /subtropical regions .Techniques which utilize estimated the Rain Induced Attenuation(RIA) for three locations of study based on the model suitable for a subtropical/tropical region and techniques that employ RIA estimations in the decision support techniques bring noticeable improvements in the SNR on satellite communication channels work on these regions. They were able to improve SNR by better tuning of parameters like transmit power, modulation, propagation angle, frequency and transmission rate.

Atta Rahman et al [68] propose a real time adaptive resource allocation scheme for OFDM system using GRBF-Neural Networks and Fuzzy Rule Base System. They designed a real time system which take CSI and QoS as input, and give optimal Modulation Code Pairs (MCPs) and power vectors for different subcarriers. Using a Fuzzy Rule Base System (FRBS), MCP by giving CSI and QoS has been obtained. Employing Differential Evolution (DE) enable to get the power vector. After training a Gaussian Radial Basis Function Neural Network (GRBF-NN) is trained in offline mode using sufficient number of such examples, given QoS and CSI as input GRBF-NN gives Optimum Power Vector (OPV) and FRBS gives optimum MCP immediately. Comparison of various other schemes of same parameter with the proposed technique by the simulations showed that the proposed scheme is supreme.

2.7 Research Gaps

After a wide-range review of the existing literature, the following gaps have been identified in the area of adaptive coding and modulation for single frequency carrier wireless systems.

1. There is a limited research done on adaptive coding and modulation as applied to single frequency carrier wireless system.
2. There is also a limited research done on mitigating propagation impairment in tropical regions based on a rain data collected from the study site.There is no such work conducted in equatorial and tropical African region including Ethiopia.
3. Mitigating rain induced attenuation using Neuro-Fuzzy based adaptive coding and modulation has not been studied adequately.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the rain attenuation and Neuro-Fuzzy based adaptive coding and modulation (ACM) employed in this research work. A rainfall attenuation based on local rain data is determined and used as input to mitigate the rain fade. An adaptive coding and modulation scheme-based controller using Neuro-Fuzzy system to achieve desired BER performance and channel data rate are investigated.

In order to mitigate fading over a time-varying channel, Neuro-Fuzzy controller is first utilized to select the desired modulation type and coding rate to maximize data rate at the receiver end while achieving the target BER. The transmitter then adapts its coding rate and constellation size depending on the channel parameters to improve the performance of wireless systems. Hence, section 3.2 present data processing; while section 3.3 covers implementation of adaptive coding and modulation; finally, the design of Neuro-Fuzzy based adaptive coding and modulation is described in section 3.4.

3.2 Rain Measurements and Data Processing

The cumulative distribution of rainfall rate (Rp) presents the rain intensity versus percentage of the time (over one year) (p) the indicated rain rate is exceeded. ITU-R[33] requires calculation $R_{0.01}$ mm/h to predict the attenuation due to rain. $R_{0.01}$ occurs at 0.01% of the time exceedance, which can be read from the ITU-R map [33] or obtained from long-term local measurements. The parameter relies on the integration time of the rainfall measuring devices used. According to most researchers finding, the preferred integration time is one minute. If one-minute rainfall data is not available which is a prevalent situation in most part of our country, converting from higher integration times to one-minute integration time is therefore required.

According to the recommendation of ITU-R rain attenuation prediction procedures [5], the most effective way of determining cumulative rainfall distribution is through direct measurement made at the site of interest. Thus, in this research work, one years (october,2017- September 2018) of one- minute rainfall rate recorded with a device installed at Jimma University, Ethiopia including rainy and non-rainy (zero value) days is utilized. Only the rain intensities with values different from zero were sorted out and processed, and then the appropriate mathematical formulation was used to calculate the desired parameters.

The procedure used to compute rain rate exceedance is listed as follows:

Step 1: - A rain data collected each minute having zero and non zero values are obtained.

Step 2: - Only a data having non zero values are taken and sorted out in ascending manner

Step 3: - Frequency of distribution is determined for a range of values with beam width of 1

Step 4: - Cumulative frequency distribution is determined using the result in step 3

Step 5: - Each cumulative distribution is multiplied by the rain rate time(which is one minute in our case and this result will be divided for)the number of minutes in a year.

Step 6: - Finally using a plot of log axis of the result obtained in previous step versus the range of values from step 2,rain rate exceeded for 0.01% is determined.

3.3 Determination of Rain Attenuation

In this thesis, the ITU-R rain attenuation model is used to determine the rain attenuation. ITU-R P.530-17 [5] under section 2.4.1describes the method for the calculation of rain attenuation over the terrestrial LOS radio systems using long-term rain statistics. The model is presented in chapter two section 2.2.3 A of this thesis.

3.3.1 The ITU-R Rain Attenuation Model

The prediction procedure outlined in ITU-R attenuation model is considered to be valid in all parts of the world at least for frequencies up to 100 GHz and path lengths up to 60 km. Thus, based on the above steps the rain attenuation is calculated for frequencies 11,15,28,38,45,60, and 72 GHz with a path length of 13.4 km.

Formulas to calculate specific attenuation is given by[40]

$$\Upsilon_R = KR^{\alpha} \tag{3.1}$$

Where Υ_R is specific attenuation, R is rain rate for 0.01% exceedance and K and α are coefficients of vertical polarization.

The constant regression coefficient values for vertical polarization of indicated frequency is presented in table below. The values are obtained from Recommendation ITU-R P.833-3[40]. Usually, 99.99%service availability in the worst month is the design objective of radio networks, which implies the network outage should not exceed 432 minutes in a year .

Table 3.1: Coefficients for K_v and α_v for indicated frequency of operation

Frequency(GHz)	K_v	α_v
11	0.01731	1.1617
15	0.05008	1.0440
28	0.1964	0.9277
38	0.3844	0.8552
45	0.5375	0.8123
60	0.8515	0.7486
72	1.0561	0.7171

Terrestrial LOS radio link performance analysis is depending on the calculations of the link budget. The link budget computation involves the calculation of received signal level, fade margin and noise figure. Therefore, the expected received signal powerP_r is computed using the following formula.

$$P_r = P_t + G_{tx} + G_{rx} - FSL - L \quad (dB) \tag{3.2}$$

where P_t is the transmitter power in output at the antenna input. This is the amount of microwave carrier output power, usually expressed in dBm; L is losses due to the presence of atmospheric gases, vegetation, buildings, clouds and fogs;G_{tx} = Transmit antenna gain, G_{rx}= Receive antenna gain, FSL = Free space path loss.

The performance of a radio link is determined by the percentage of the time the signal will be below the threshold of the radio receiver relative to the total time period. Therefore, the fade margin, which is the difference between the receiver nominal signal level and the receiver threshold level, has to be calculated as follows:

$$FadeMarigin = RSL - R_{XTH}(dB) \tag{3.3}$$

where RSL is the received signal level and R_{TXH} is the receiver threshold.

The performance of a communication system is estimated based on the achievable signal-to-noise (SNR) at the receiver. The term SNR (in dB) refers to the estimation of signal strength as a function of signal degradation and background noise. This power can be expressed as

$$\frac{S}{N} = \frac{C}{N} = \frac{(P_t G_{tx} G_{rx})}{(KTBL_{sys})}(\frac{\lambda_0}{4\pi d})^2 \tag{3.4}$$

where L_{sys} is system loss at the receiver and transmitter;λ_0= free-space wavelength (m); Gtx and Grx are transmitting and receiving antenna gain respectively; K is the Boltzmann's constant = 1.38x10^{-23} J/ K; B = bandwidth (Hz);and d is the link distance (m). T is the system effective noise temperature (K) which is defined as:

$$T = T_A + T_R \tag{3.5}$$

where: T_A is antenna noise temperature (ambient noise) and T_R is the receiver noise temperature (internal noise), both are in the unit of Kelvin. It must be noted that TR is often expressed as the receiver's noise figure in dB. Note that the relationship between the carrier frequency (GHz) and wavelength in meter is expressed as

$$\lambda_0(m) = \frac{0.3}{f(GHz)} \tag{3.6}$$

To express the above equation in decibel the equivalent expression is presented as:

$$\frac{S}{N} = \frac{C}{N} = P_t + G_{tx} + G_{rx} - FSL(dB) - L(dB) - 10\log_{10} B(dBm.Hz) + 174(dBm) \tag{3.7}$$

$$\frac{S}{N} = P_r - 10\log_{10} B(Hz) + 174 \qquad (dBm) \tag{3.8}$$

WhereP_r is determined from the link profile given parameters.

In practical communications systems it is usually desired to have the received power level greater than the threshold level required for the minimum acceptable quality of service (usually expressed as the minimum carrier-to-noise ratio (CNR), or minimum SNR). This design allowance for received power is referred to as the link margin, and can be expressed as the difference between the design value of received power and the minimum threshold value of receive power[69]:

$$Linkmargin(dB) = LM = P_r - P_r(min) \quad (3.9)$$

where is all quantities are in dB.

Link margin should be a positive number; typical values may range from 3 to 20 dB. Having a reasonable link margin provides a level of robustness to the system to account for variables such as signal fading due to weather, movement of a mobile user, multipath propagation problems, and other unpredictable factors that can degrade system performance and quality of service. Link margin that is used to account for fading effects is sometimes referred to as fade margin.The fade margin

$$P_r = R_{XTH} + FadeMarigin \quad (3.10)$$

In this case FadeMarigin = Link Margin, and $R_{XTH} = P_r(min)$

Satellite links operating at frequencies above 10 GHz, for example, often require fade margins of 20 dB or more to account for attenuation during heavy rain[73].The link budget tells us that link margin improvement for a given communication system can be done by increasing the received power (by increasing transmit power or antenna gains), or by reducing the minimum threshold power (by improving the design of the receiver, changing the modulation method, or by other means). Increasing link margin therefore usually involves an increase in cost and complexity, so excessive increases in link margin are usually avoided.Thus, the SNR when there is rain in a path between transmitter finally computed and used as input for adaptive coding and modulation system.

3.3.2 SNR Calculation

The signal-to-noise ratio of the particular radio link whose radio link profile has been defined in Table 3.2 is computed as follows.The computation is based on the values given in the link profile and the result from rain attenuation determination using ITU-R model.

i) Clear Air SNR calculation:-The received signal is determined using equation 3.2. Substituting the values from the link profile table,Table 3.2, we get a -68.9 dB received signal level at the receiver end.Since the threshold received signal level is given and equal to -76.2dB, the link margin can be calculated using equation (3.3).Hence, the link margin for this particular microwave link is equals to 31.8 dBm or 8.1dB.

The SNR of this link at a clear sky environment can be determined using equation (3.8) as :

$$\frac{S}{N} = P_r - B(dB.Hz) + 174dBm \tag{3.11}$$

whereP_r =31.8dBm and B=21.7MHz .Thus, SNR is equal to 32.53dB.

ii) Rainy time SNR calculation:- Here the received signal is additionally degraded by the total rain attenuation amount.Thus The,P_r will be -38.1dBm -57.625dBm which is -95.75dBm. The Fade Marigin is similarly computed using equation(3.3) except at this link condition the received signal is equals to -95.75dBm.Finally,the SNR for different fading depth(rain rate) is computed.

Table 3.2: Link parameters for terrestrial line of sight networks

Parameters	Link Jimma	Link Muja
Antenna height	10	10
Antenna gain(dBi)	42	42
Tx line unit loss($\frac{dB}{100}$)	4.53	4.53
Tx line loss	0.91	0.91
Frequency(GHz)	11	11
Circuit branching loss(dB)	6.8	6.8
True azmuth	203.92	23.91
Vertical angle	1.48	-1.59
Link distance (km)	13.4	
Free space loss (dB)	139.6	
Rx threshold level (dBm)	-76.2	
Effective frequency spacing (MHz)	21.7	
Atmospheric absorption loss (dB)	0.35	
Tx power (dBm)	30	

3.4 Implementation of Adaptive Coding and Modulation

According to the proposed block diagram shown below in Figure 3.1, the randomly generated data source is encoded using a feed-forward convolutional encoder with different coding rates and then the convolutionally encoded data is modulated by M-QAM. The encoded and modulated symbols are transmitted.Finally, white Gaussian noise is added to the transmitted signal.

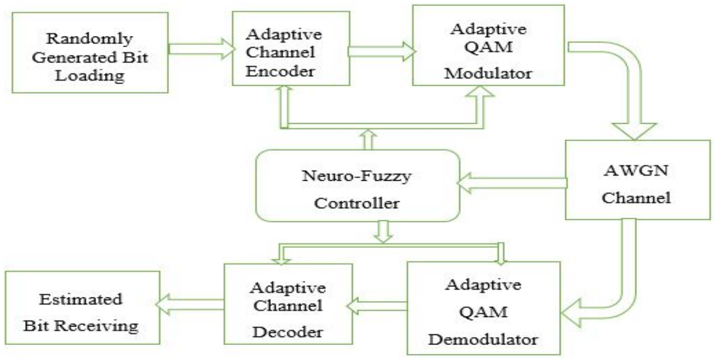

Figure 3.1: Neuro-Fuzzy based ACM block diagram

At the receiver side, after conversion of the analog signal back to a digital format, the received data is demodulated using an adaptive MQAM demodulator. Following this, the convolutionally encoded bits are decoded using Viterbi decoder so as to remove the redundant bits added for the purpose of error correction.

Practically, the designed system is incapable of regenerating the transmitted message signal as it is because of the noise superimposed on the wireless medium. It is obvious to have some bits received in error. By changing the modulation order and coding rate BER is computed for each SNR based on the system parameters shown in Table 3.2. The comparison of the performance of BER for adaptive coding and modulation techniques is studied. Comparison of Adaptive modulation with fixed coding and adaptive coding and modulation is also analyzed.

Table 3.3: System parameters and values

Schemes	**Parameter values**
Modulation order	4QAM,8QAM,16QAM,32QAM,64QAM, 128QAM,256QAM,512QAM and 1024QAM
SNR	0 to 35 dB
Target BER	10^{-6} to 10^{-2} bits/sec/Hz
Coding-rate	1/4, 1/3, 1/2, 2/3, and 3/4
spectral efficiency	0.5 to 7.5bits/sec/Hz
Constraint length	3
Channel model	AWGN

3.4.1 Neuro-Fuzzy Based Adaptive Coding and Modulation Design

Neuro-fuzzy system is a combination of neural network and fuzzy inference system (FIS), having the combined benefits of both a fuzzy inference system (FIS) and neural network by utilizing neural learning methods in adjusting the membership function parameters and the structure of the FIS.

Usually, it has the advantage of allowing an easy transformation of the final system into a set of if-then rules, and the fuzzy system can be seen as a neural network structure with knowledge distributed throughout connection strengths. Using this hybrid soft computing method, an initial fuzzy logic model with its input parameters is first obtained from the input-output data of the designed adaptive coding and modulation system. A neural network is then applied to update the initialized fuzzy rules and membership functions to create the final neuro-fuzzy method. In this neuro-fuzzy approach, back propagation learning and the least squares method is used to update membership functions and adjust design parameters respectively.The general neuro-fuzzy approach system flowchart is shown in Figure 3.2 below.

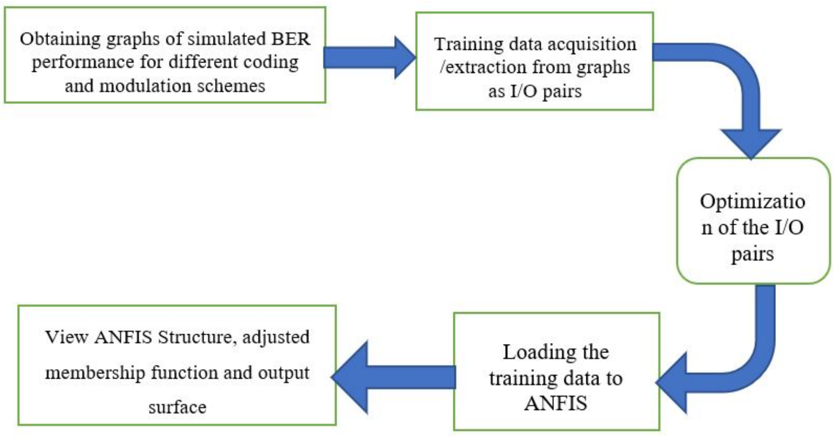

Figure 3.2: Neuro-Fuzzy based system model flow chart

In the following section, each step which are incorporated into the proposed Neuro-Fuzzy system model will be discussed briefly. Hence, section 3.3.1 presents the generation of I/O data pairs; section 3.3.2 explain spectral efficiency or data rate optimization; section 3.3.3 shows Neuro-Fuzzy architecture for ACM; finally, this chapter is completed by describing how the designed ANFIS system is trained.

3.4.1.1 Generation of Input / Output data pairs

The proposed neuro-fuzzy system must be trained by a manually generated data from the graph of simulated adaptive coding and modulation for single frequency carrier system.

Figure 3.3 shows how the desired coding rate and modulation order graph coordinate that fulfill different target bit error rate values such as 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3},and 10^{-2}demands.

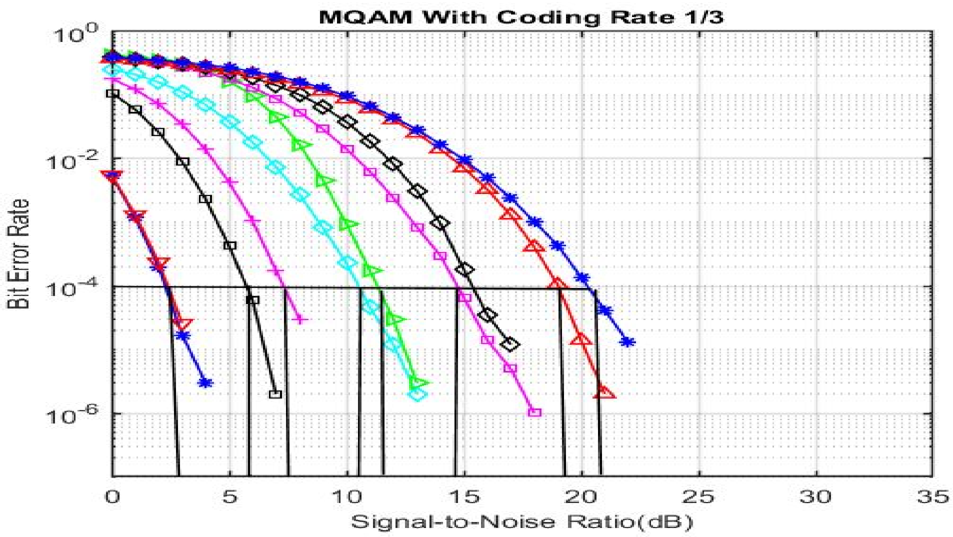

Figure 3.3: Generation of I/O pairs for different modulation schemes with 1/3 code

Table 3.4: Sample of I/O data pairs obtained from graph resulted from simulation

Input	**Output**			
SNR(Eb/No)	BER	Modulation Type	Coding Rate	Max. Data Rate (Bits/sec/Hz)
3.5	10^{-3}	4QAM	1/4	0.5
4.5	10^{-3}	8QAM	1/3	1
9.9	10^{-4}	16QAM	1/2	2
12.9	10^{-2}	32QAM	2/3	3.33
16.5	10^{-3}	64QAM	3/4	4.5
20.7	10^{-2}	128QAM	2/3	4.667
24	10^{-4}	256QAM	2/3	5.33
25.6	10^{-4}	512QAM	3/4	6.75
27.45	10^{-6}	256QAM	2/3	5.33
29.8	10^{-5}	1024QAM	3/4	7.5
31.5	10^{-5}	1024QAM	2/3	6.67
32.96	10^{-6}	512QAM	2/3	6

These pairs are obtained using two methods: one is by drawing a straight line from the given SNR to the target quality of service points; the other one is by running a MATLAB command called “ginput”and take the value of the coordinate at a target BER value. The output is taken as the product of code-modulation pairs.

Table 3.3 shows a sample of I/O data pairs that are obtained as a function of SNR, BER, modulation order and coding rate to select the best modulation and coding rate to maximize the spectral efficiency of the wireless system. All the input-output data pairs are not important only those that maximize the throughput are taken based on the spectral efficiency optimization.

3.4.1.2 Spectral Efficiency Optimization

Assuming fixed transmit power, optimization of spectral efficiency (η) for adaptive coding and modulation is given by:

$$max\eta = R_C \log_2(M) \text{ such that } \overline{BER}(\overline{\Upsilon}) \leq BER_T \tag{3.12}$$

where$\overline{\Upsilon}$ is average SNR,R_C is code rate,$\overline{BER}$is average BER and M is modulation order. The target of any communication designer is to have a communication link that operates at or below the specified target BER.

In order to achieve the maximum throughput in the adaptive coding and modulation scheme, the following consideration should take into account:

1. For the same BER and SNR pair, better throughput is selected.
2. For the same data rate, less modulation and coding rate is chosen that demand less SNR.
3. The lookup table scheme may not have a complete number of data pairs, then those missed parts are completed by the expert knowledge.

3.4.2 ANFIS Architecture for Adaptive Coding and Modulation

In this thesis, a type of neuro-fuzzy method termed Adaptive Network-based Fuzzy Inference System (ANFIS) is used for modeling. MATLAB Neuro-Fuzzy designer app has been used to carry out and test the ANFIS system as a development tool. The tool consists of a fuzzy logic designer, membership function editor, rule editor, neuro-fuzzy designer, rule and surface viewers.

The fuzzy logic designer is a GUI tool that illustrates general information of a fuzzy inference system. The membership function editor displays and edits all of the membership functions associated with all of the input and output variables. The rule editor allows a designer to build fuzzy rules automatically. The rule viewer gives a better description and interpretation of all the FIS rules.

The neuro-fuzzy designer has several features. It is used to load FIS training, save the trained FIS, open a new Sugeno-type system, generate the FIS, view the ANFIS structure or any other GUIs to interpret the trained FIS model and test and validate the ANFIS model using another data. It can also allow loading the test data for validation purpose, load the pre-defined

FIS designed by the Fuzzy Logic designer, plot the loaded train data, plot the train data against the test data for comparison. The output surface viewer is a three-dimensional plot which represents a mapping of input variables to the output variable.

3.4.2.1 ANFIS System for Training Process

Enhancement of data rate using ANFIS has been developed and examined as depicted in figure 3.2. The architecture of the ANFIS used to achieve the spectral efficiency has been developed and investigated as shown in Figure 3.4. 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 is generated from simulations of the OFDM system using parameters depicted in Table 311.

Both the fuzzy logic system principles and learning capabilities of neural networks are being employed to construct ANFIS. At the initial stage, a basic fuzzy logic system controller is built to utilize the linguistic fuzzy rules. Then, the IO data pairs are used to train the ANFIS controller.

The steps involved in the ANFIS training process are:

Step1: - Loading the I/O training data;

Step2: - Generate an initial fuzzy inference system model;

Step3: - View the FIS model structure;

Step4: -Select the FIS model optimization method (hybrid method);

Step5: - Choose the training epochs and training error tolerances;

Step6: -Train ANFIS and view adjusted membership functions and output surface.

Finally, after the FIS training process are completed validation of the trained system must be carried out. The trained FIS is validated using a testing or checking data that differs from the one you used to train the FIS. In this research work validation is done using the data that is generated using the MATLAB data extraction method. These test data is a BER value for each integer value of SNR in the range 0to 35 dB and the associated modulation code pair and data rate.

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 quantifiable. To get this a logarithmic operation is performed as given in the following equation:

$$BER = \log_{10} 10^{-p}, p = 2,3,4,5,6 \quad (3.13)$$
$$BER = -P$$

In this thesis, 225 first order Sugeno-type fuzzy inference rules have been constructed as follows

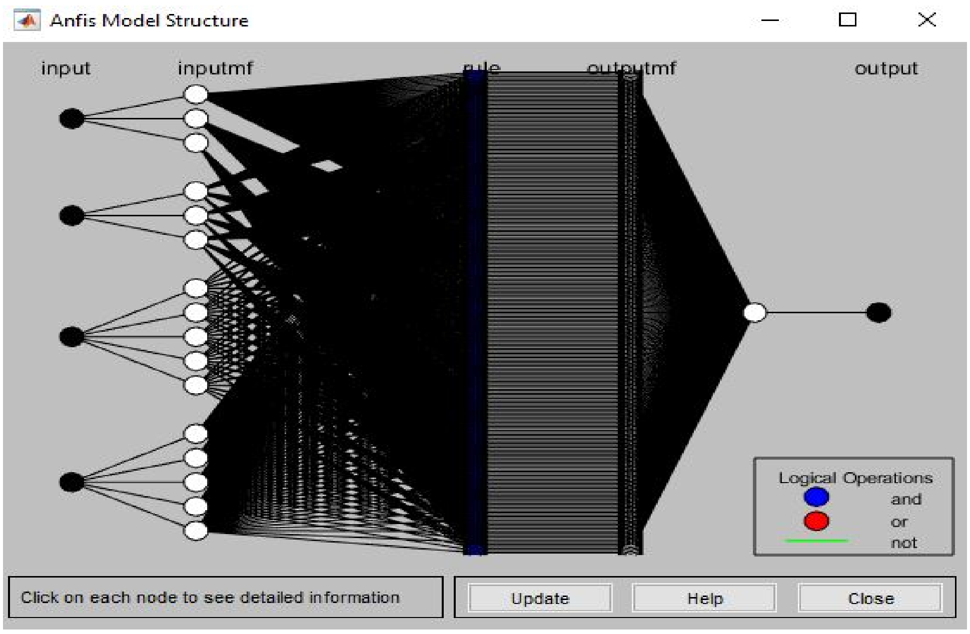

Figure 3.4: ANFIS structure with four inputs and one output

for the proposed neuro-fuzzy based ACM.This means, the multiplication of the number of membership function of the four input parameters i.e 3*3*5*5=225 rules. The general rule:

$$if x_1\ is\ A_{i1}\ AND\ x_2\ is\ A_{i2}\ AND\ x_3\ is\ A_{i3}\ AND\ x_4\ isA_{i4}\ then \quad (3.14)$$
$$f_1 = p_i x_1 + q_i X_2 + t_i x_3 + s_i x_4 + r_1 i$$

The specific rules:

$$IF\ x_1\ is\ A_{11}\ AND\ x_2\ is\ A_{12}\ AND\ x_3\ is\ A_{13} AND\ x_4\ is\ A_{14}\ THEN \quad (3.15)$$
$$f1 = p_1 x_1 + q_1 x_2 + t_1 x_3 + s_1 x_4 + r_1$$
$$IF\ x_1\ is\ A_{21}\ AND\ x_2\ is\ A_{22}\ AND\ x_3\ is\ A_{23}\ AND\ x_4\ is\ A_{24}\ THEN \quad (3.16)$$
$$f1 = p_2 x_1 + q_2 x_2 + t_2 x_3 + s_2 x_4 + r_1$$

where:

1. p_i, q_i, t_i, s_i and r_i are design parameters,
2. f_i are the outputs within the fuzzy area specified by the fuzzy logic rules,
3. A_{ij} are the fuzzy sets/membership functions for each input variables, and
4. x_i is the input parameters to the neuro-fuzzy system and i = 1,2,3, …

Layer 1 -Input node: - Each node in this layer is an input node, that corresponds to one input parameter. These nodes pass the input signals to the layer 2. The proposed fuzzy sets have three membership function for the input variables SNR and BER designated as low, medium and high and five membership function for the input variable modulation order (MOD) and code rate represented as *very low, low, medium, high, and very high*. The output of the neuron i in the input node is obtained as:

$$O_i^1 = f_i^1(net_i^1) = net_i^1 \tag{3.17}$$

where net_i^1 is the i^{th} input to the node of layer one.

Layer 2- Input membership layer: Each node in this layer acts a linguistic label of one of the input variables in input node, i.e., specifies the membership functions for each input parameters. The generalized bell-shaped membership function is used to represent each fuzzy set variables. The output of neuron j in the layer 2 is given by:

$$O_j^2 = f_j^2(net_2^2) = \frac{1}{1+(\frac{x-C_j}{a_j})^{2b_j}} \tag{3.18}$$

where a_j, b_j and c_j are parameters set that define shapes of j^{th} membership function. The parameter b_j is usually positive and the parameter c_j locates the center of the curve.

Layer 3-Rule layer: - All the nodes in this layer calculates the firing strength of a rule via multiplication. Each node takes four inputs, to form 225 nodes in layer 3 and creates a fuzzy rule for all input variables. The output of the neuron k is obtained as follows:

$$O_k^3 = f_k^3(net_k^3) = net_k^3 \tag{3.19}$$

$$net_k^3 = \prod_j w_{jk}^3 y_j^3 \tag{3.20}$$

where y_j^3 is j^{th} input to the node layer 3 and $w_j k^3$ is assumed to be unity.

Layer 4-Output membership function:- Neurons in this layer represent fuzzy sets used in the consequent fuzzy inference rules. An output membership neuron receives inputs from the corresponding fuzzy rule neuron and combines them by using the fuzzy operation union. The output of neuron m is given by:

$$O_m^4 = f_m^4(net_{km}^4) = \max(net_{km}^4) \tag{3.21}$$
$$net_{km}^4 = O_k^3 w_{km}$$

where w_{km} is the output action of the m^{th} output associated with k^{th} rule.

Layer 5- Defuzzification layer: - in this layer the sum-product composition is used to find the defuzzified output, i.e., crisp value. It calculates the output as the weighted average of the centroids of all output membership functions.

$$O_o = f_o^5(net_o^5) = net_o^5 \tag{3.22}$$
$$net_o^5 = \frac{\sum_m O_m^4 a_{cm} b_{cm}}{\sum_m O_m^4 b_{cm}}$$

where a_{cm} and b_{cm} are centers and widths of the output fuzzy sets respectively. The values of b_{cm} is assumed unity.

The Sugeno type FIS editor with four inputs and one output is shown in Figure 3.5.

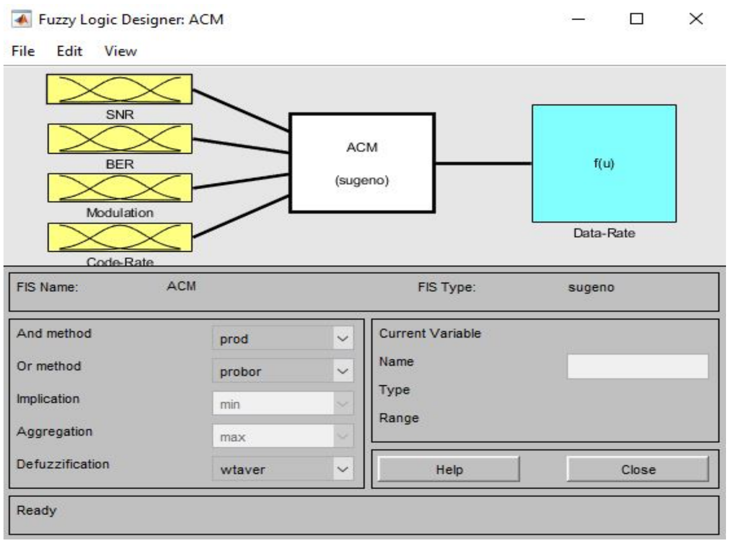

Figure 3.5: Sugeno type FIS with 4 inputs and one output

In a fuzzy logic system, the fuzzy sets of each input variable are specified by membership functions. A membership function is a curve that maps each input element to a membership value between 0 and 1.In the designed ANFIS system, because of its smoothness, bell-shaped membership functions are considered for all IO variables.

The number of membership functions is chosen so as to cover the entire input space. For SNR input, *low, medium and high* membership functions are considered as shown in Figure 3.6.

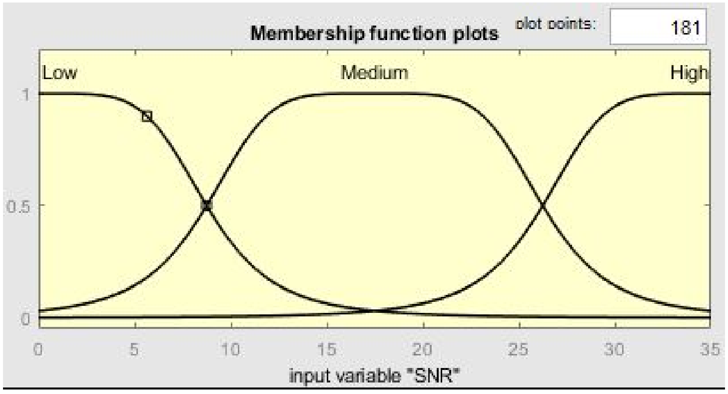

Figure 3.6: SNR membership functions

The input parameter BER has also three membership function designated as *low,medium and high* which cover equally spaced value in between -6 to -2.This membership function representation in fuzzy logic designer is depicted as follows in Figure 3.7.

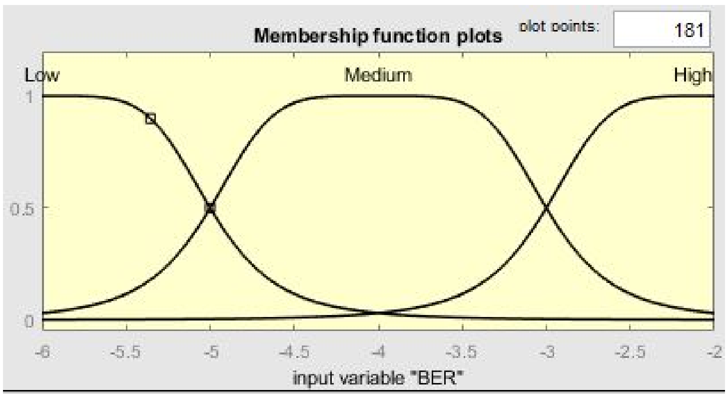

Figure 3.7: Input BER membership functions

For the modulation order input, five membership functions are taken namely very low, low, medium, high, and very high as shown in Figure 3.8. The modulation schemes are 4QAM, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM and 1024QAM with 1, 2, 3 to 9 number of bits per each modulation scheme respectively.

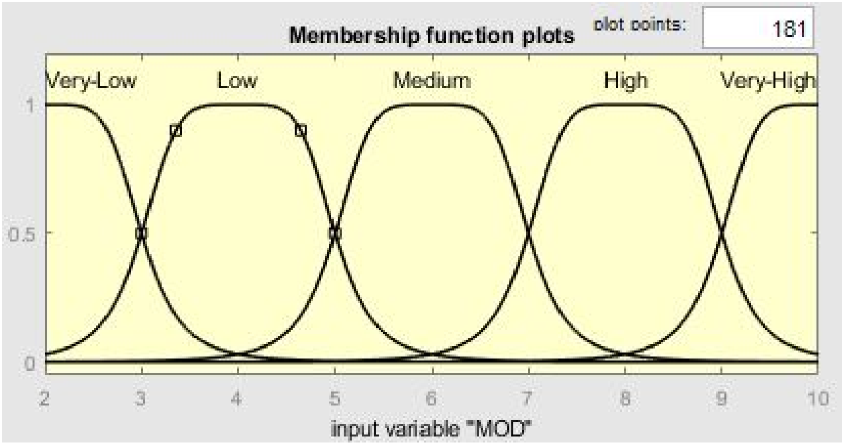

Figure 3.8: Membership functions of input modulation

Figure 3.9 shows the membership functions of the input variable code rate with a range of 0.25 to 0.75. It contains five membership function like input variable modulation type designated as very-low, medium, high and very-High membership functions. The output of the neuro-fuzzy model has only one membership function i.e. data rate.

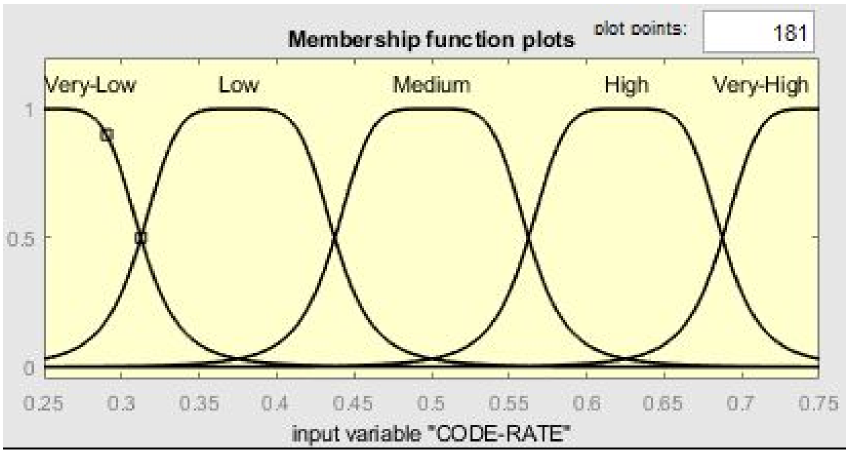

Figure 3.9: Membership functions of code rate

CHAPTER 4

RESULT AND DISCUSSION

This research work has been carried out using MATLAB 2018a simulation software. In this simulation work,

- For a BER vs SNR performance simulation analysis of different modulation schemes and coding rates, 10 million random bits are exploited.
- Perfect knowledge of the channel state information (CSI) at the receiver is assumed.
- At any point of distance, the power of the signal is assumed to be more than that of the noise signal, i.e. the SNR is assumed greater than 0dB.
- The designed system under investigation is a single frequency carrier communication system.

4.1 Rain Attenuation Results

In this section, results of the collected rain data analysis are presented. $R_{0.01}$, specific attenuation, total attenuation at$R_{0.01}$ are analyzed for different frequency of operation above 10 GHz and for a microwave link distance of 10km to 50 km.

Table 4.1: Specific rain attenuation and Total rain attenuation values at $R_{0.01}$ and path distance 13.4 km

Frequency(GHz)	Specific Attenuation(Υ_R) (dB)	Total Rain Attenuation($A_{0.01}$)(dB)
11	4.201	27.65
15	6.97	46.14
28	15.768	95.71
38	21.91	129.19
45	25.01	145.49
60	29.32	165.50
72	31.33	172.40

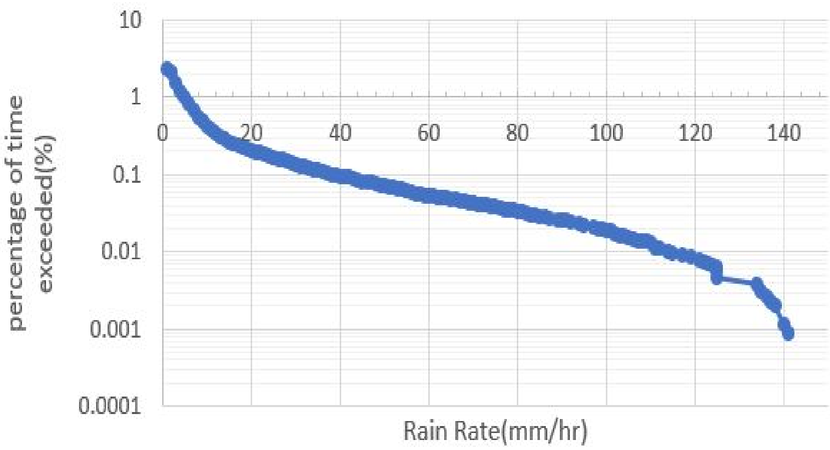

Figure 4.1: Rain rate versus percentage of time exceeded($R_{0.01}$)

Figure 4.1 depicts rain rate versus percentage of time exceeded. Based on computation carried out using ITU-R rain induced attenuation model, the $R_{0.01}$ is 113mm/hr.

Figure 4.2 illustrates the relationship between specific attenuation (Υ_R) and frequency of operation at a$R_{0.01}$equals to113mm/hr. It is seen from the graph that as the frequency of operation increase the specific attenuation also increases simultaneously. This implies that as we increase the frequency of operation the impact of rain attenuation increases.

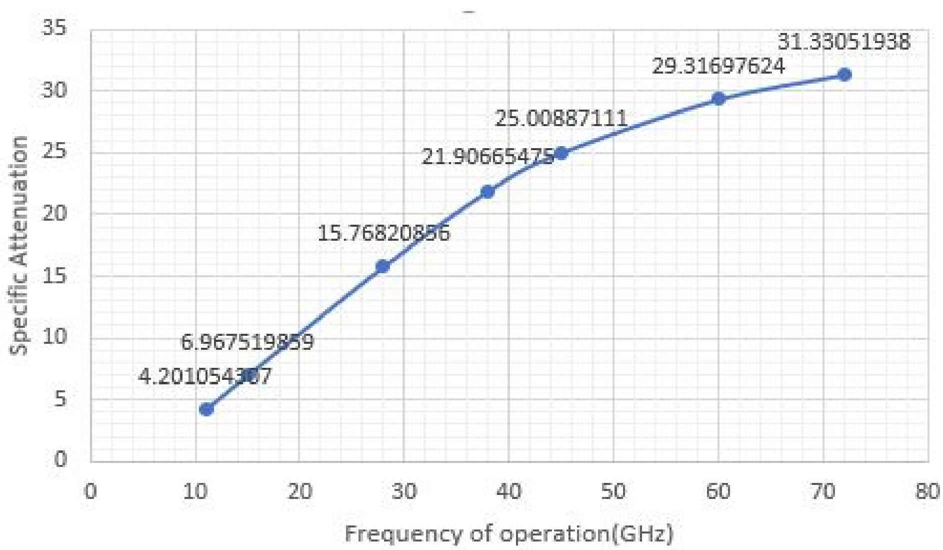

Figure 4.2: Frequency of operation versus specific attenuation(Υ_R)

Figure 4.3 below describes the impact of over all rain induced attenuation at a frequency of operation above 10 GHz. The trend that are presented in the graph demonstrates that rain

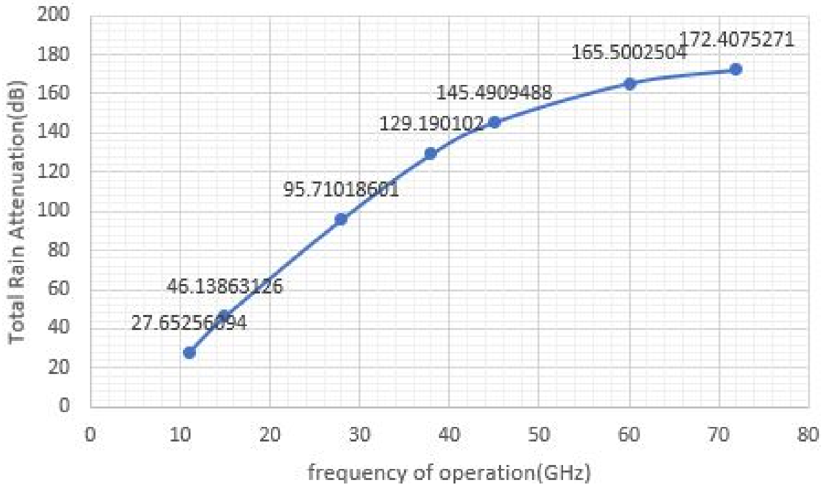

Figure 4.3: Rain Attenuation at a $R_{0.01}$ versus frequency of operation above 10 GHz

attenuation increases sharply as the frequency of operation above 10 GHz tends to increase. For instance, 27.55 dB ,45.14, 95.71 dB, 129.19 dB and 145.49 B rain induced attenuation is experienced at a frequency of operation 11GHz, 15GHz, 28GHz,38GHz and 45GHz respectively.

In figure 4.4, the relationship between total attenuation and radio link distance between transmitter and receiver is presented.The total rain attenuation sharply rises as te distance between the transmitter and receiver increases.It is observed that, 27.55 dB,39.47dB, and 76.2dB attenuation is encountered at a link distance of 10km,20km, and 30km respectively.

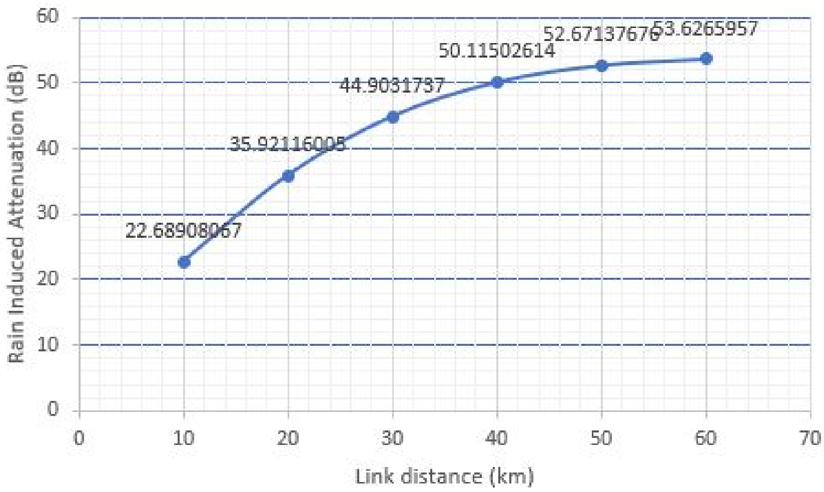

Figure 4.4: Link distance Vs Rain Attenuation at rain rate $R_{0.01}$ and frequency of operation 11GHz

4.1.1 Signal Level Analysis

From the computation procedure outlined in section 3.32, it is known that the clear sky(non-fading channel condition) situation the received signal level at the receiver end using a transmitting power of 30dBm is -38.1 dBmfor the link between Jimma and Muja. From the link profile

Table 4.2: Rain attenuation related results

Rain Rate(mm/hr)	Attenuation($A_{0.01}$)	Received signal(P_r)	Fade Marigin	S/N
1	0.576323852	-68.76632385	37.43367615	31.86367615
2	0.860605856	-69.05060586	37.14939414	31.57939414
3	1.145049792	-69.33504979	36.86495021	31.29495021
4	1.423380619	-69.61338062	36.58661938	31.01661938
5	1.696576566	-69.88657657	36.31342343	30.74342343
10	3.014356383	-71.20435638	34.99564362	29.42564362
15	4.287171504	-72.4771715	33.7228285	28.1528285
20	5.535420522	-73.72542052	32.47457948	26.90457948
25	6.767708859	-74.95770886	31.24229114	25.67229114
30	7.988611848	-76.17861185	30.02138815	24.45138815
35	9.200903025	-77.39090302	28.80909698	23.23909698
40	10.40641245	-78.59641245	27.60358755	22.03358755
45	11.60642176	-79.79642176	26.40357824	20.83357824
50	12.80186904	-80.99186904	25.20813096	19.63813096
55	13.99346486	-82.18346486	24.01653514	18.44653514
60	15.18176223	-83.37176223	22.82823777	17.25823777
65	16.36720128	-84.55720128	21.64279872	16.07279872
70	17.55013878	-85.74013878	20.45986122	14.88986122
75	18.7308685	-86.9208685	19.2791315	13.7091315
80	19.9096356	-88.0996356	18.1003644	12.5303644
85	21.08664703	-89.27664703	16.92335297	11.35335297
90	22.26207928	-90.45207928	15.74792072	10.17792072
95	23.43608423	-91.62608423	14.57391577	9.003915771
100	24.60879358	-92.79879358	13.40120642	7.83120642
105	25.78032239	-93.97032239	12.22967761	6.659677614
110	26.95077178	-95.14077178	11.05922822	5.489228216
115	28.1202312	-96.3102312	9.889768803	4.319768803
120	29.28878011	-97.47878011	8.721219891	3.151219891
125	30.4564895	-98.6464895	7.553510495	1.983510495
130	31.62342306	-99.81342306	6.38657694	0.81657694

given in Table 3.2 , it is observed that the receiver threshold signal level value is -76.2 dBm.. Therefore, by applying (3.3), the fade margin is equal to -38.1 dBm. This implies that, if the fade depth is between 0 and -38.1 dBm, there is faded reception due to poor signal level. If the fade depth is less than -38.1 dBm, it will results in network outage.

From Table 4.2 we can see that as the rain rate increases the total rain $A_{0.01}$ attenuation is increased and the received signal level and signal-to-noise ratio is decreasing.For instance, for rain rate 5mm/hr,25mm/hr, 50mm/hr, 100mm/hr and130mm/hr the receiver detects a SNR value of 30.74dB, 25.67dB,19.64dB, 7.83dB and 0.8165dB respectively.When the rain rate is above 130mm/hr,the resulting SNR at the receiving end reduced below 0dB.This implies that, total network outage will happen when the rain rate is above 130mm/hr.

4.2 Simulation Result of ACM Performance

4.2.1 BER Performance Results

In this section, performance plots of BER vs SNR for different modulation schemes are studied with various code rates under AWGN transmission medium. Each plot in these graphs represents the BER performance of a specific modulation- code pair.

As has been seen from the graphs in figure 4.5 BER decline dramatically as the SNR tends to increase. The lower modulation order and coding rates provide better performance with less SNR. On the contrary, when the received SNR is high, a higher order modulation and higher coding rate schemes gives a good performance. However, the plots of BER performance for

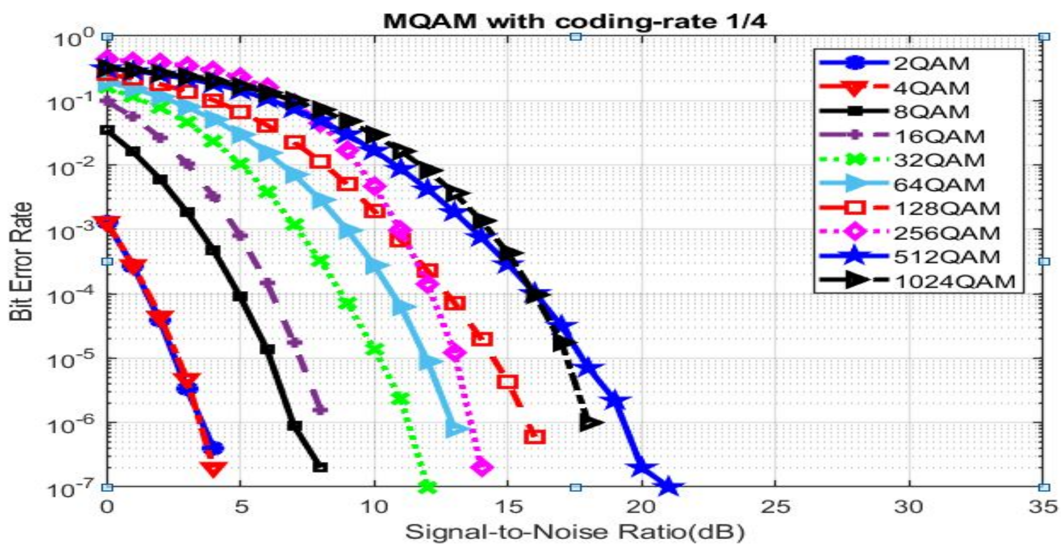

Figure 4.5: BER Vs SNR for different M-ary QAM with 1/4 code rate

modulation schemes 2QAM and 4QAM are overlapped. As it is clearly indicated, in ACM technique design, a modulation scheme having a better spectral efficiency over the same SNR range is selected. Thus, 2QAM is not used in the Neuro-Fuzzy based ACM fade mitigation implementation.

Figure 4.6 demonstrate SNR vs BER graphs for different M-ary QAM with 1/3 coding rate. In order to achieve a target QoS, higher SNR is required with 1/3 coding rate compared to FEC of 1/4 coding rate. For instance, for 1024QAM modulation scheme to achieve a target QoS 10^{-6} it requires less than 20dB when its FEC is 1/4 and more than 20 dB when the FEC is 1/3.

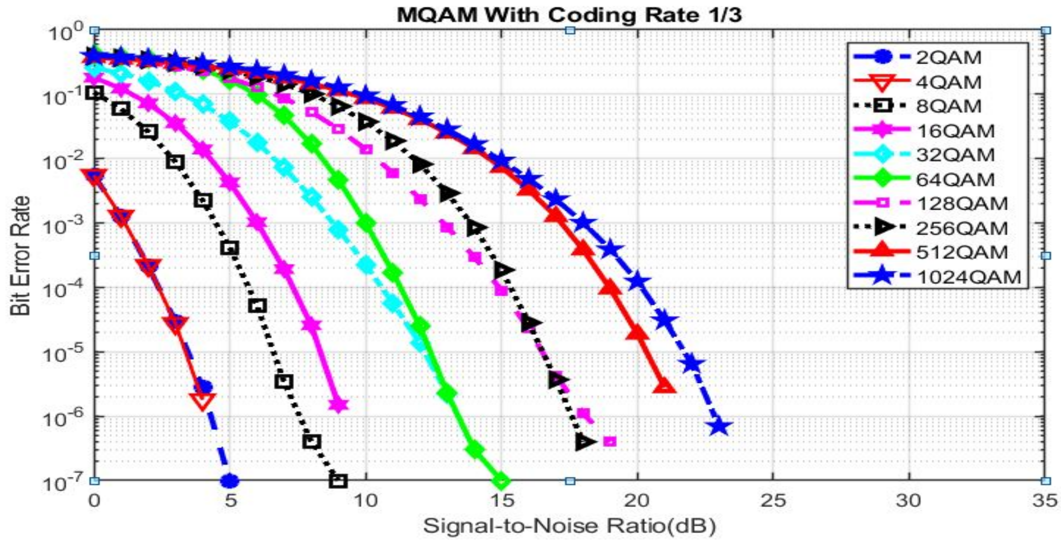

Figure 4.6: BER Vs SNR for different M-ary QAM with 1/3 code rate

As it can be seen from the result, for a target BER 10^{-5} and below, for the same values of SNR utilizing 64QAM and 256QAM outperform 32QAM and 128QAM respectively in terms of spectral efficiency.

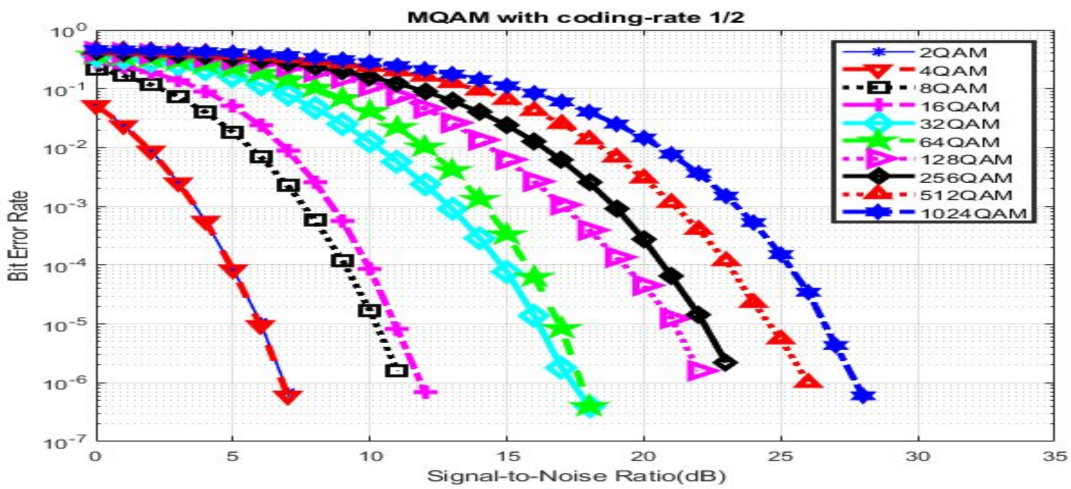

Figure 4.7: BER Vs SNR for different M-ary QAM with 1/2 code rate

The BER performance for various modulation schemes with 1/2 coding rate under AWGN channel is shown in Figure 4.7. The BER curves indicate that by increasing the code rate increases the required SNR to operate for a system.

The BER performance comparison for various M-ary QAM using rate 2/3 and 3/4 convolutional codes is shown in Figure 4.8 and Figure 4.9 respectively. In general, each modulation scheme with code rate 2/3 and 3/4, as the SNR increases the higher modulation order performs better than the lower one for the same target BER.

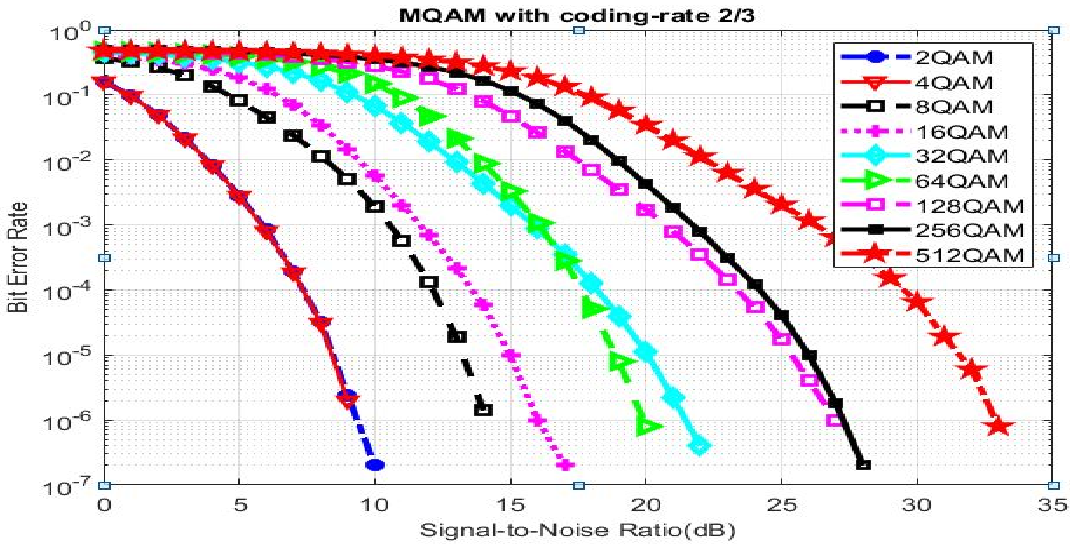

Figure 4.8: BER Vs SNR for different M-ary QAM with 2/3 code rate

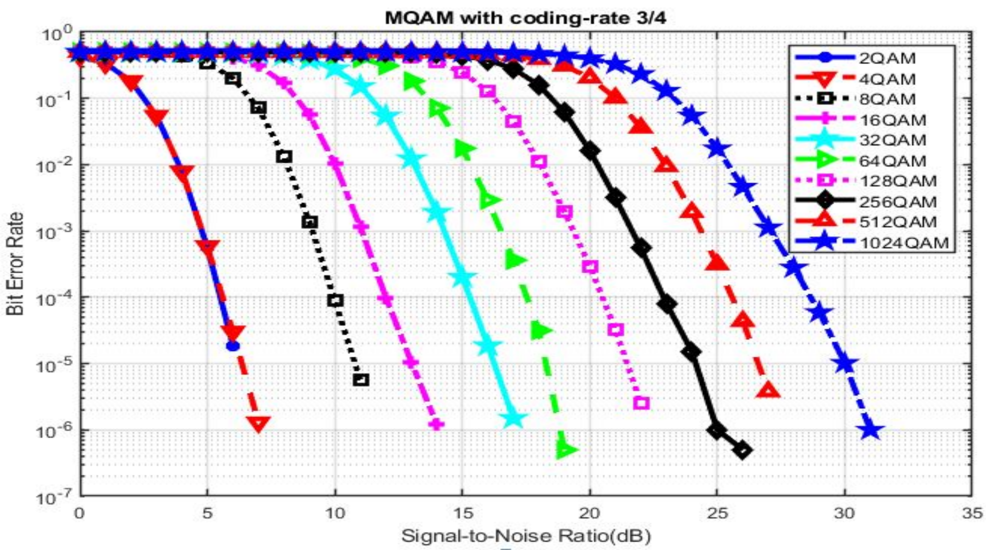

Figure 4.9: BER Vs SNR for different M-ary QAM with 3/4 code rate

The selection of the modulation order and coding rate depends on the quality of the wireless channel. The bandwidth efficient modulation and coding techniques are used during a good channel condition. On the other hand, lower coding and modulation scheme are used to improve the BER performance for less SNR. For example, for SNR of 20dB and target BER of 10^{-4}, 64QAM with 2/3and 128QAM with 3/4 code rate can be employed to improve capacity and maintain link.

From the rain data analysis ,it is known that for less rain condition, in which the rain rate is in between 5 to 25 mm/hr, the SNR is degraded less.In this range of rain rate the SNR is in the range 25-30dB.This implies that,using modulation scheme likee 128QAM,256QAM and 512QAM is appropriate to achieve high data rate.On the contrary, for the rain rate above 105mm/hr the SNR is reduced and become below 6dB which is a deep fade condition.In this situation ,it is recommended to use a lower order modulation scheme like 2QAM,4QAM, 8QAM along with a low coding rate like 1/4 and 1/3.

4.2.2 Effect of Channel Coding

The designed ACM system performance due to different FEC is analyzed below for a target BER $10^{-2}$and 10^{-5}. BER 10^{-5} is usually taken as a comparison of various modulation schemes[54] in digital communication systems. Thus, in this section comparison of different QAM modulation schemes with respect to coding rate and SNR is presented.

Table 4-3 shows the required SNR to meet the target BER= $10^{-2}$for various constellation sizes with 1/4, 1/3, 1/2, 2/3, and 3/4 code rates. The higher modulation schemes require higher SNR. In addition, increasing the code rate increases the required SNR to meet the target QoS for each modulation order.

Figure 4.10 shows a graphical representation of table 4.2. The graph depicts the required SNR to get the target BER of 10^{-2} for various modulation schemes with different code rates as tabulated in Table 4-3. Lower order modulation schemes (4QAM,8QAM and 16QAM) can perform at a lower SNR values with the indicated coding rates. However, Higher order modulation such as, 512QAM and 1024QAM do not operate for lower SNR values. In other words, to meet a target BER, higher modulation and coding is used during a good channel condition. Conversely, when the channel condition become attenuated severely utilization of low order modulation schemes recommended to maintain link availability.

Figure 4.11 shows the plots of the required SNR to meet the target BER of $10^{-5}$for various

Table 4.3: Required SNR for a set of code rates for target BER=0.01

Modulation scheme	**1/4**	**1/3**	**1/2**	**2/3**	**3/4**
2QAM	2.68	0	1.9	3.82	3.84
4QAM	2.68	0	1.9	3.83	3.85
8QAM	1.5	2.85	5.62	8.1	8.2
16QAM	3	4.25	6.8	9.4	8.18
32QAM	4.95	6.6	10.2	12.9	13.1
64QAM	6.6	8.45	12	13.8	15.3
128QAM	8.22	10.4	14.4	17.4	18.15
256QAM	9.4	11.75	16.2	18.8	20.3
512QAM	10.8	14.55	18.4	22	23
1024QAM	11.7	14.87	20.7	23.7	25.43

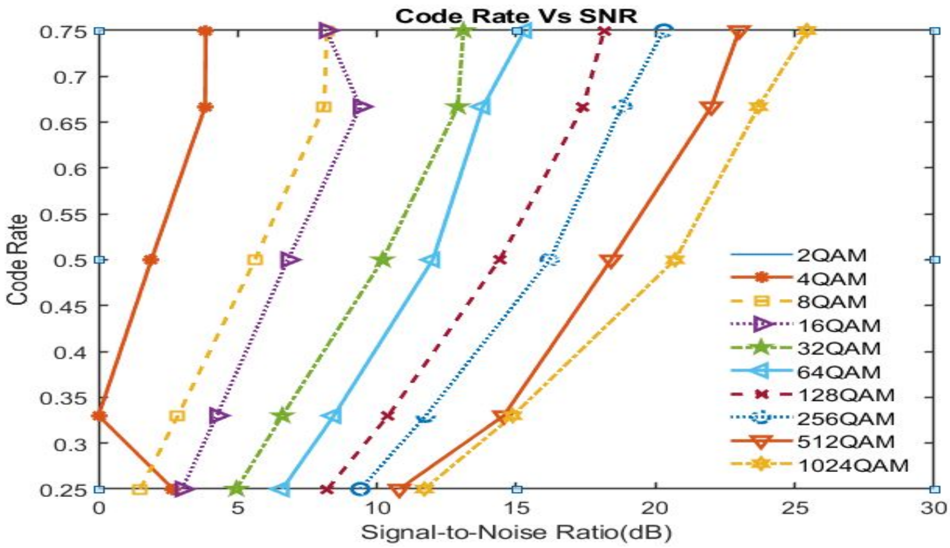

Figure 4.10: Code rate Vs SNR for different modulation schemes for target bit error rate of 10^{-2}

modulation schemes with various code rates as tabulated in Table 4-4. Since BER $=10_{-5}$ is very much lower than BER$=10_{-2}$ it is expected that the SNR required to achieve BER $=10_{-5}$ is higher than that of BER$=10^{-5}$.This is seen from Figure 4.11.

Figure 4.12 and Figure 4.13 shows the bit error rate comparison of 16QAM and 256QAM with different coding rates respectively. For the same modulation order, the BER performance varies with coding rate. By reducing the code rate, less SNR is required to meet the desired target BER.

For a low QoS less SNR is required compared to high QoS for the same code-modulation pair. For example, for 16QAM with 1/2 code rate, 6.8dB,8.6dB,9.9dB,10.9dB and 11.9dB

Table 4.4: Required SNR for a set of code rates for target BER=0.00001

Modulation scheme	**1/4**	**1/3**	**1/2**	**2/3**	**3/4**
2QAM	0	3.29	6	8.3	6.37
4QAM	0	3.3	6	8.3	6.37
8QAM	6.1	6.56	10.2	13.2	10.8
16QAM	7.25	8.4	10.9	15	10.8
32QAM	10.1	12.2	16.17	20.2	16.2
64QAM	11.93	12.39	16.9	18.8	18.47
128QAM	14.45	16.49	21.1	25.36	21.4
256QAM	13	16.5	22.2	26.2	24.17
512QAM	17.76	20.3	24.5	31.5	26.6
1024QAM	17.2	21.75	26.6	31.5	29.98

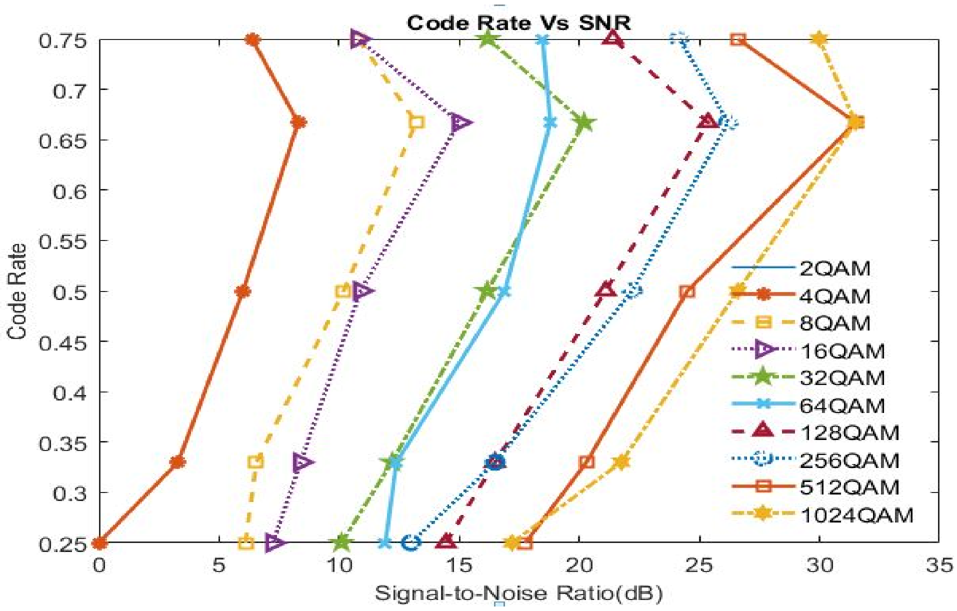

Figure 4.11: Code rate Vs SNR for different modulation schemes for target bit error rate of 10^{-5}

SNR is required to meet the bit error rate of 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}, as seen from Figure 4.12.Whereas, from figure 4.13 we can seen that 16.2dB,18.9dB,20.65dB, and 22.2dB is required to achieve a QoS 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5} respectively.

As it can be seen in the figure 4.12 and 4.13, for a target bit error 10^{-3} and less the performance of FEC 3/4 is better than FEC 2/3 in terms of achieving high spectral efficiency for the same value of SNR. For instance, to achieve a target BER 10^{-5} a SNR less than 10.8 dB and 25dB is required for 16QAM and 256QAM with FEC 3/4respectively; whereas 15 dB and 26.6 dB required for 16QAM and 256QAM with FEC 2/3.

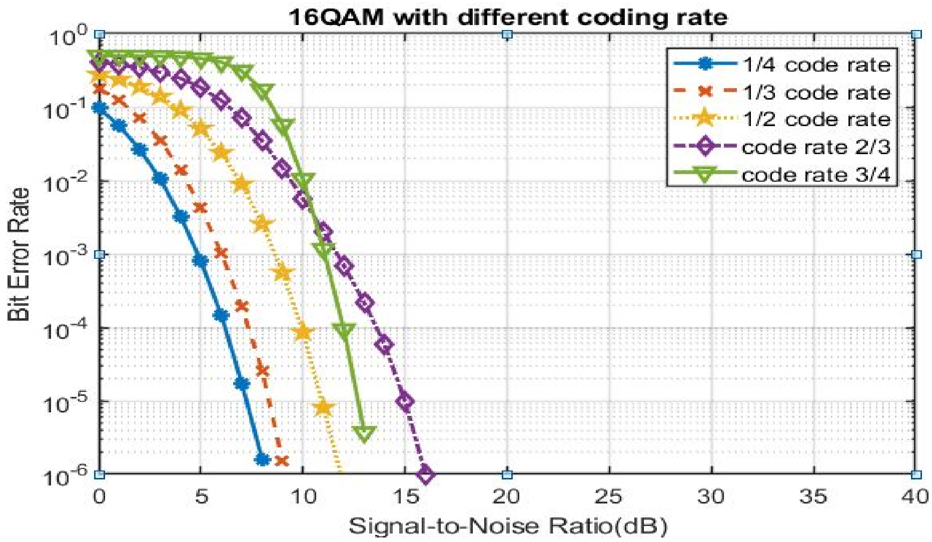

Figure 4.12: BER Vs SNR for 16QAM for different coding rate

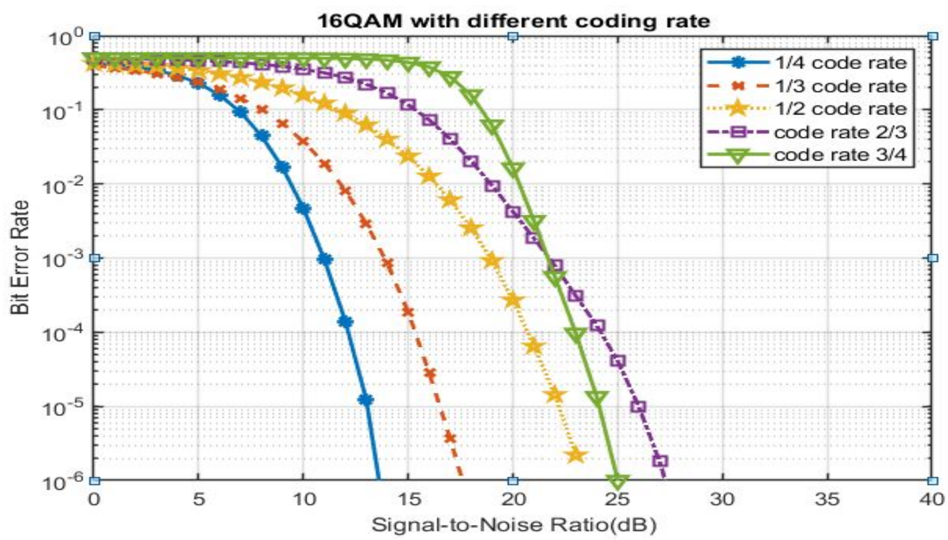

Figure 4.13: BER Vs SNR for 256QAM for different coding rate

To achieve a low BER ,it is necessary to have a good reception at the receiving end which results in high SNR.This can be satisfied when the channel condition is non-fading or clear sky.For the link between Jimma and Muja the calculated SNR is 32.5dB.In this channel quality, a high quality of service and a high data rate can be achived by employing a larger constellation size modulation scheme i.e 256QAM,512QAM and 102QAM with a high coding rate like 2/3 and 3/4.Even if there is a degradation of received signal when there is a rain in between this link, it can achieve a high data rate in a rain rate below 20mm/hr.

4.2.3 Spectral Efficiency Results

The spectral efficiency with various SNR range for different modulation and coding techniques over AWGN channel is presented in this section. The range of SNR switching thresholds for various coding and modulation with target BER of10^{-2} and $10^{-5}$is shown in Table 4-5. These SNR values are used to select the appropriate code modulation pair for the adaptive coding and modulation schemes.

Table 4.5: Range of SNR values that give a target BER of 10^{-2} and 10^{-5}

BER=10^{-2}				BER=10^{-5}			
SNR range (dB)	Modulation	Code Rate	Data Rate	SNR range (dB)	Modulation	Code Rate	data Rate
<1.9	4QAM	1/2	1	3.3-6.1	4QAM	1/3	0.66
33-3.85	16QAM	1/3	1.33	6.1-6.37	8QAM	14	0.75
3.85-6.6	4QAM	3/4	1.5	6.37-10.8	4QAM	3/4	1.5
6.8-8.45	16QAM	1/2	2	10.8-16.2	16QAM	3/4	3
9.4-11.75	16QAM	2/3	2.66	16.2-18.47	32QAM	2/3	3.75
12-12.9	64QAM	1/2	3	18.47-21.4	64QAM	1/2	4.5
13.8-15.3	64QAM	2/3	4	21.4-24.17	128QAM	3/4	5.25
15.3-17.4	64QAM	3/4	4.5	24.17-26.6	256QAM	3/4	6
17.4-18.1	128QAM	3/4	5.25	26.6-29.98	512QAM	3/4	6.75
18.8-20.3	256QAM	3/4	5.33	>29.98	1024QAM	3/4	7.5
20.3-23	256QAM	3/4	6				
23-25.43	512QAM	3/4	6.75				
>25.43	1024QAM	3/4	7.5				

The spectral efficiency(bits/sec/Hz) performance comparison with fixed and adaptive techniques with a target BER of 10^{-2} and10^{-5} are shown in Figure 4.14 and Figure 4.15 respectively based on Table 4-5.

The spectral efficiency when SNR with 3/4 coding rate for 4QAM, 16QAM, 64QAM, 265QAM and 1024QAM is more than 10.8dB, 16.2dB, 21.4DdB,26.6dB and 29.98dB respectively.

. What we have seen from the above figures is that, the spectral efficiency is proportional to the estimated SNR. In fixed coding and modulation technique, the throughput achieved at some SNR value, then while the received SNR tends to increase the spectral efficiency remain constant. Moreover, increasing the constellation size (modulation order) with coding rate increase the performance of wireless systems. For example, 256QAM with 3/4 coding rate has higher throughput than the lower code-modulation pair schemes such as 4QAM-3/4.This implies that

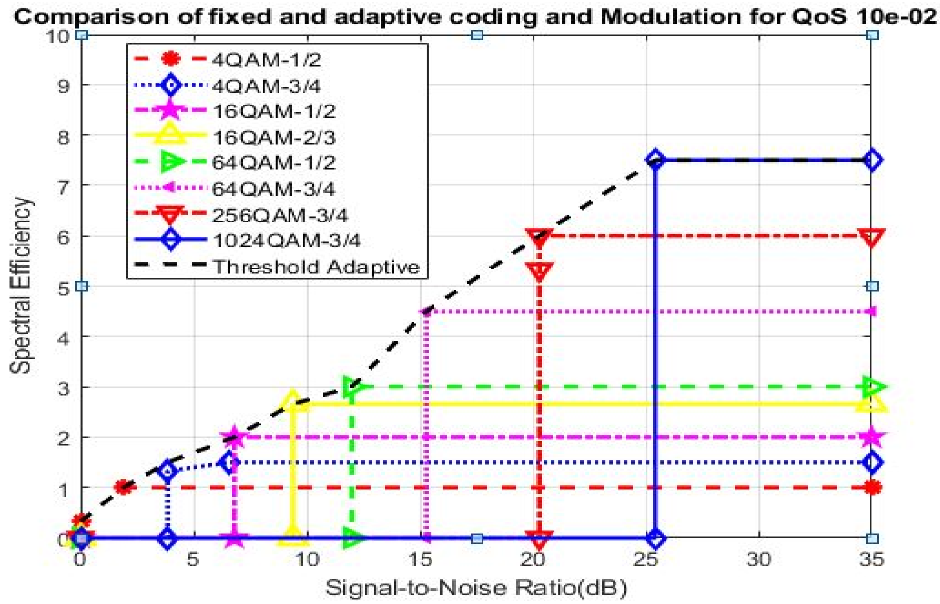

Figure 4.14: Spectral efficiency Vs SNR for BER of 10^{-2} for fixed and adaptive coding and modulation schemes

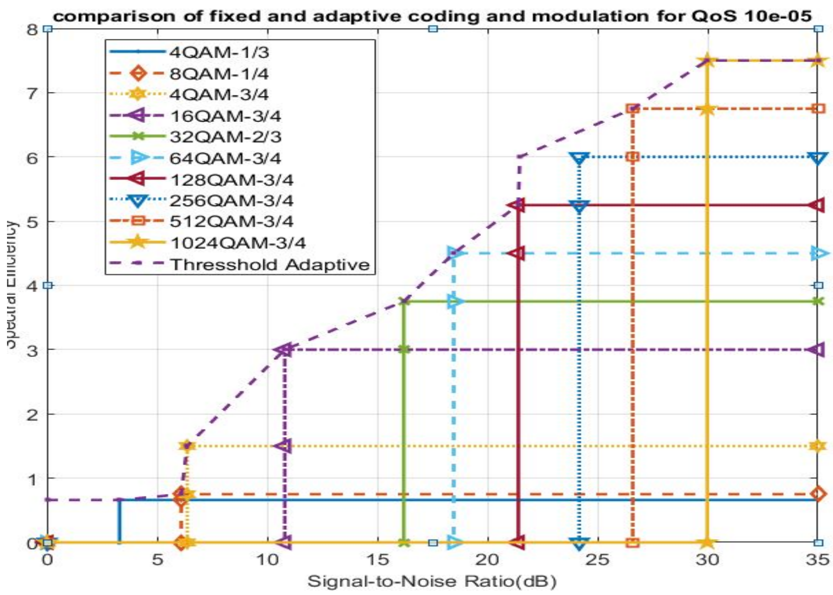

Figure 4.15: Spectral efficiency Vs SNR for BER of 10^{-5} for fixed and adaptive coding and modulation schemes

when the channel condition is good,the receiver receives higher SNR,it is better to use larger constellation size of modulation scheme with higher coding rate.In contrast,while the channel quality is bad,the receiver receive low SNR level, it is better to use more robust modulation scheme having small constellation size with low coding rate.

In other word, 512QAM and 1024QAM with coding rate2/3 and 3/4 is used when the rain rate is less(i.e 0-25 mm/hr) to achieve a high spectral efficiency and high QoS.By using a medium constellation size modulation order,64QAM, 128QAM, and 256QAM, with coding rate 1/2 and 2/3 ,the link availability is sustained and achieve a moderate spectral efficiency in the channel condition when the rain rate is in between 30-80mm/hr.However, while the rain rate is increased above 80mm/hr the adaptive coding and modulation system is forced to use a lower order modulation scheme (i.e 32QAM,16QAM,8QAM) so as to kept the wireless link alive by reducing the data rate .Finally, when the channel condition become more worse , more priority is given to sustaining the link availability than achieving high spectral efficiency.Thus for a rain rate above 110mm/hr a more robust lower constellation size modulation type with a coding rate 1/4 is used.

4.2.4 Parameter Selection to Maximize Spectral Efficiency

In this thesis, ACM of a single frequency carrier system is simulated under an AWGN channel. For each given SNR a BER is computed. The given SNR are investigated for each modulation order and coding rate. Hence, the spectral efficiency of an adaptive coding and modulation scheme for the designed single frequency carrier systems is dependent on the BER, SNR, coding rate and modulation order.

Table 4.6: Neuro-fuzzy parameters and their corresponding values

Input Variables	**ACM parameters**	**Values**
	SNR	0-35dB
	Modulation Scheme	4QAM,8QAM,16QAM,32QAM, 64QAM,128QAM,256QAM' 512QAM,1024QAM
	Coding Rate	1/4,1/3,1/2,2/3,and 3/4
Output Variables	**Spectral Efficiency**	0.5-7.5bits/sec/Gz

The parameters that are used as input and output in ANFIS training along with their respective values are tabulated in table Table 4-6.

$$\eta = f(BER, SNR, m, R_C) \tag{4.1}$$

where$m = \log_2(M)$, M is the modulation/constellation size and R_C is the FEC convolutional coding rate.

It is known that from previous sections ,SNR is directly dependent on the channel condition.The channel condition in turn is dependent on rain rate that are found in the path between transmitter and receiver of the link.As a result, rain rate is an input parameter to the Neuro-Fuzzy based adaptive coding and modulation system.

4.3 Neuro-Fuzzy Based System Results

The value of epoch and error tolerance are set to 50 and 10_{-4} as tolerance error and in the ANFIS training process. The output is selected based on the constructed 225 fuzzy rules. Figure

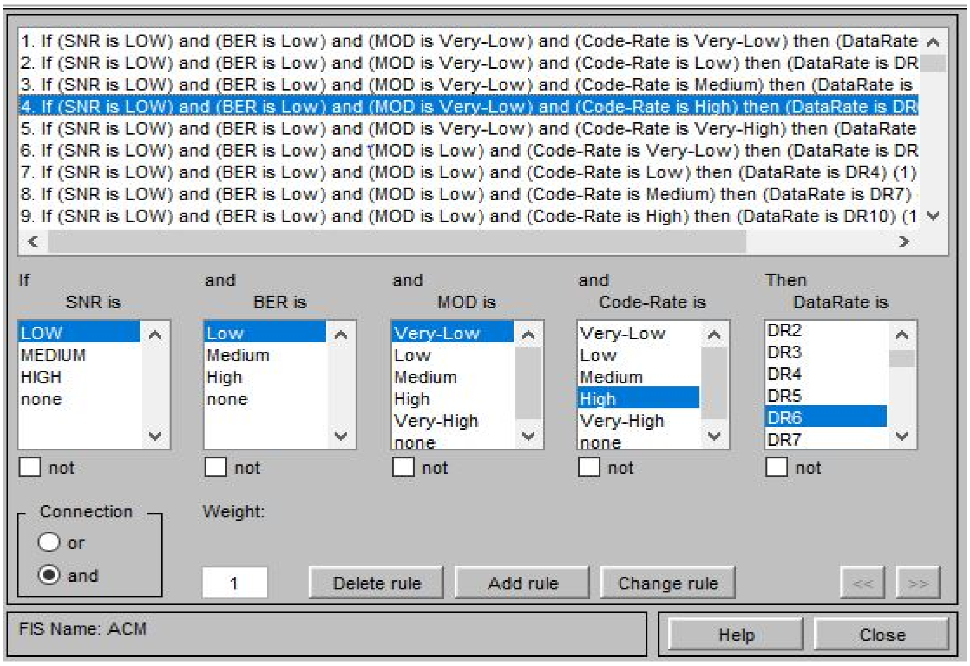

Figure 4.16: Rule editor of fuzzy inference system

4.16 shows the neuro-fuzzy based rule editor. In this system the if-then rules are used to make decision in data rate optimization.

The ANFIS rule viewer is shown in Figure 4.17 and it gives a better description of all fuzzy rules. The first four columns indicate the membership functions of the input parameters and last column is the output data rate/spectral efficiency membership function.

Figure 4.18 to 4.23 show different surface views. These 3D curves represent mapping of input variables against output variable. In other words, it dictates the smoothness and correlation between the input variables to select the desired output at a particular time depending on the quality of the channel. The output axis describes the spectral efficiency result of the two other input combination. The surface colors indicate the level of the output. As shown in all figures, the

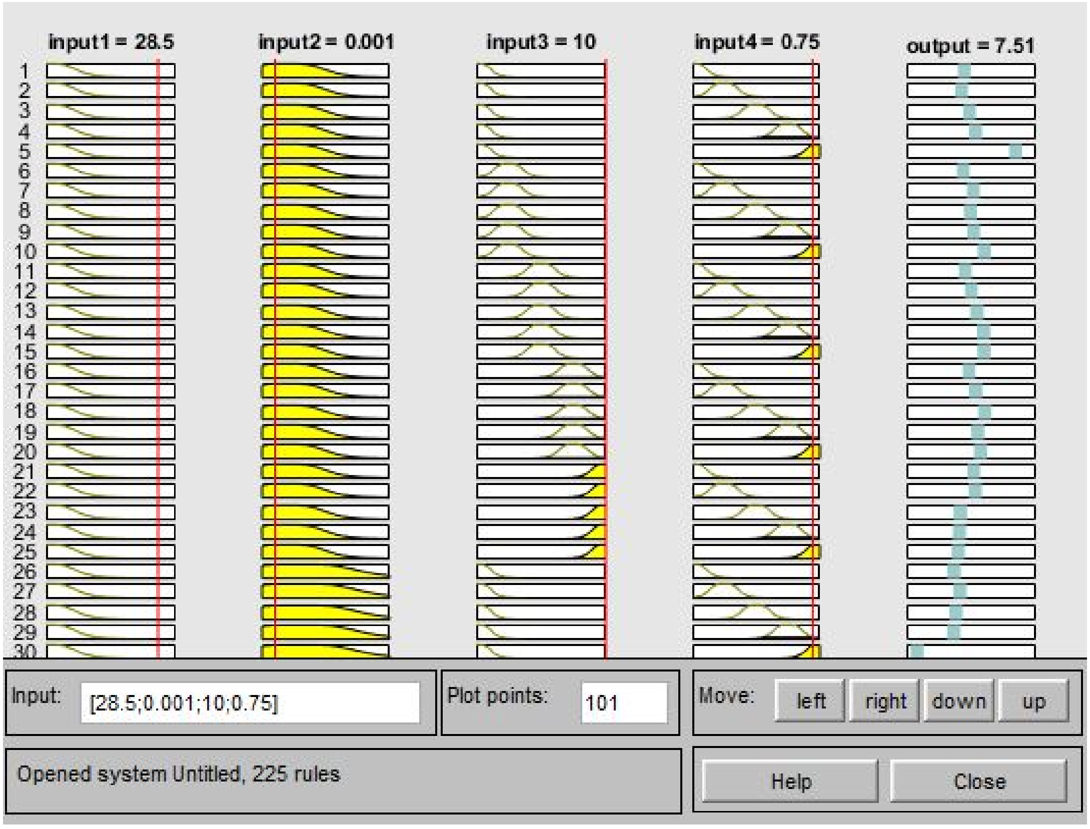

Figure 4.17: Rule viewer of fuzzy inference system

yellow, light blue and dark blue colors show the data rate is high, average and low, respectively.

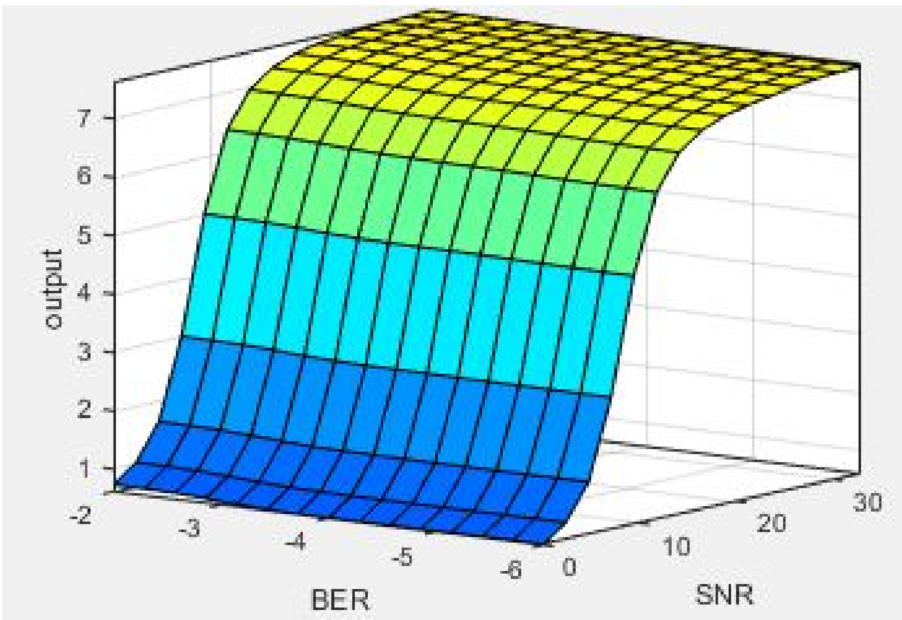

Figure 4.18: ANFIS surface view for BER Vs SNR

The surface view of combined effect for both SNR, and BER is shown in Figure 4.18.This surface view is displayed by the ANFIS surface viwer when the modulation order and the coding rate are fixed as 10 and 0.75 respectively.As this two fixed parameters change the view changes simultaneously. It indicates that by increasing the SNR the data rate is also increased. In addition to this, for a poor QoS, the spectral efficiency is higher compared to a low target BER. For a BER of 10-3 and SNR of 28.5dB, a data rate of 7.5 bits/sec/Hz can be achieved. It is seen from figure 4.17, which is taken from the ANFIS rule viewer, it gives a data rate of 7.51 which is almost equal to the theoretical value.

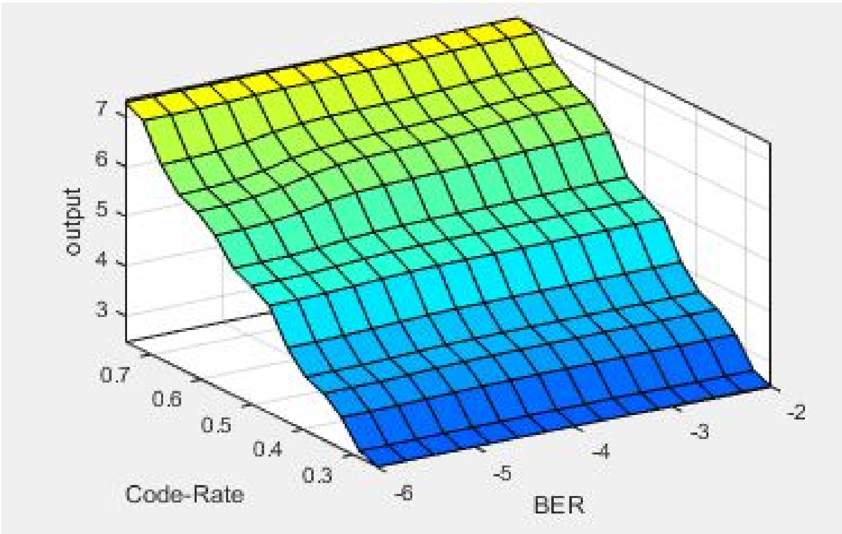

Figure 4.19: ANFIS surface view for BER Vs Code-Rate

Figure 4.19 is a surface view of BER versus coding rate while SNR =16.5 dB and modulation order value of 10. It is seen that as the coding rate tends to increase, the data rate also increased in proportional way. Data rate can also be improved by raising the modulation order and coding rate as shown in Figure 4.20.

The two controlled input variables SNR and coding rate are fixed to a value of 16.5 dB and 0.75 respectively while evaluating BER versus Modulation relationship. The stepsize like graph in figure 22 implies that as the coding rate increases the achievable data rate also increases simultaneously.The lower coding rate,coding rate 1/2 and 1/3, allows to achieve a lower data rate as it can be seen from blue color.Where as a higher data rate can be achieved using high coding rate(i.e. 2/3 and 3/4)as it is seen from yellow color.

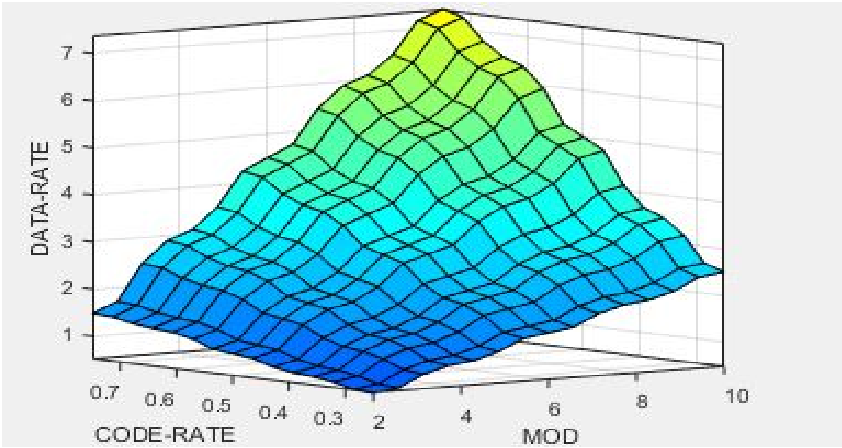

Figure 4.20: ANFIS surface view for MOD Vs Code-Rate

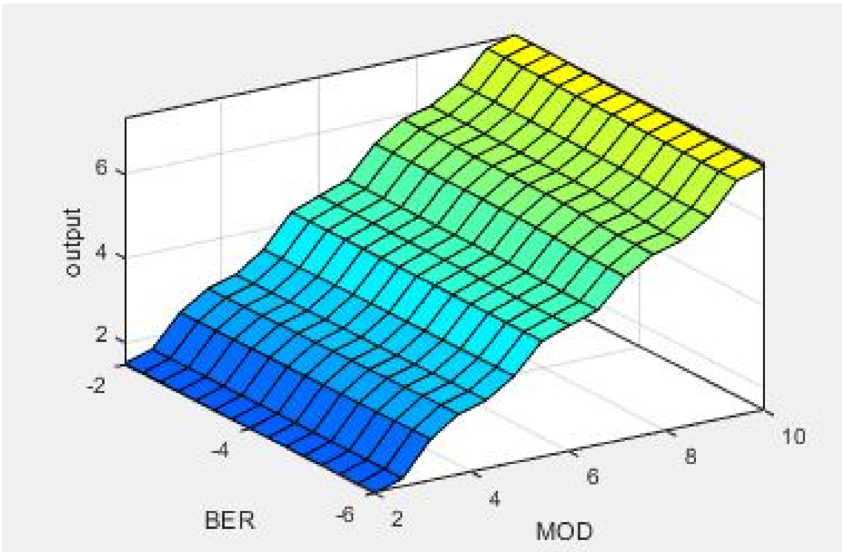

Figure 4.21: ANFIS surface view for BER Vs MOD

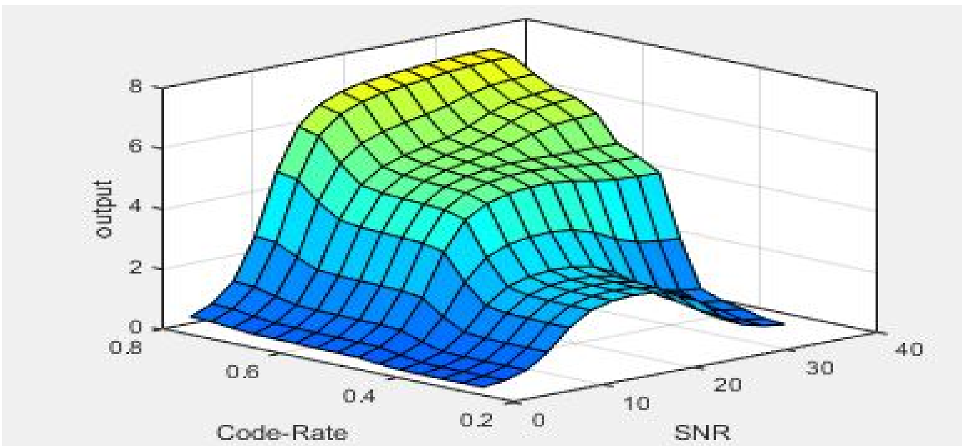

Figure 4.22: ANFIS surface view for SNR Vs Code-Rate

In the SNR and Modulation ANFIS input relationship, the blue color tells that for high SNR value(clear sky good channel condition) lower order modulation scheme is not selected.In this type of channel condition , higher order modulation scheme like 256QAM, 512QAM, and 1024QAM are employed to attain higher data rate as it is indicated by yellow color region.On the contrary ,when the channel quality is lower(rain time) a lower constellation size modulation scheme(4QAM,8QAM,16QAM) are used to sustain link availability by penalizing data rate.

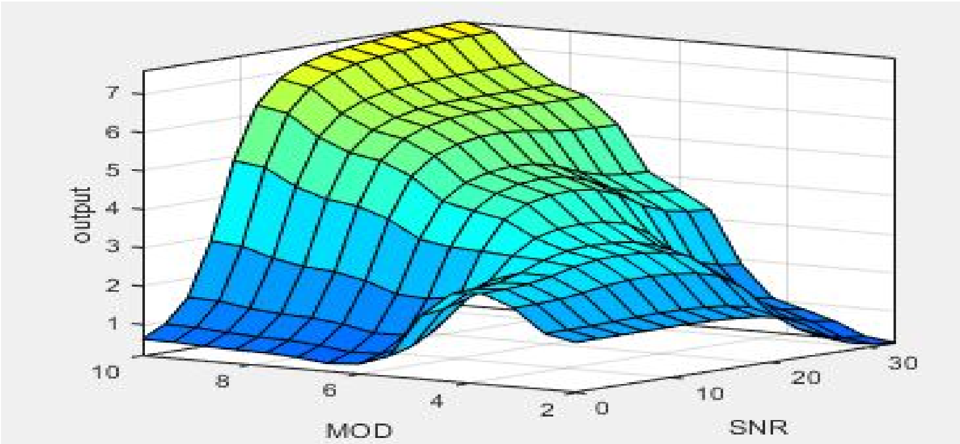

Figure 4.23: ANFIS surface view for SNR Vs Modulation

4.3.1 Performance Comparison of the ANFIS to Various Schemes

The simulation results show that the proposed scheme perfoms better compared to the other techniques in terms of spectral efficency or data rate for a target BER of 10-2 and fixed trasnmit power. Thus, system performance is maximized by varying code rate and modulation scheme such that the BER and total transmitted power remain under certain thresholds.Figure 4.22 showed that the graph grows smoothly in spectral efficiency as the SNR increases compared two the other two.This implies that the the adaptation capability of Neuro-Fuzzy based ACM system in response to varying channel condition is suprem.

Table 4.7: Data rate comparison of the proposed scheme to different existing models at atarget BER=10^{-2}

Scheme	SNR					
	5dB	10dB	15dB	20dB	25dB	35dB
Neuro-Fuzzy based ACM	1.6	5.84	7.2	7.5	7.5	7.5
Fuzzy based ACM	1.1	2	3.9	5.8	6.7	7.5
Switching thershold based ACM	1.5	2.66	5.25	6.9	7.5	

At SNR range 5 dB to 25 dB, a neuro-fuzzy based adaptive coding and modulation shows superiority in spectral efficiency compared to fuzzy logicbased ACM, switching threshold based adaptive coding and modulation. Table 4-5 shows the data rate comparison of the proposed scheme to different existing models for SNR 5dB, 10dB, 15dB , 20dB, 25dB and 35dB.

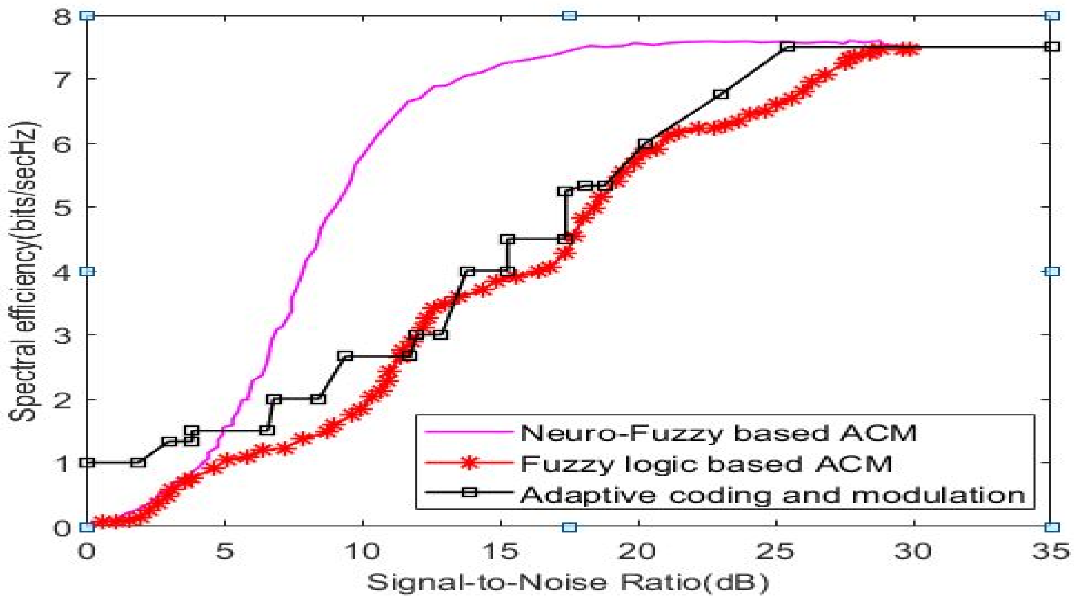

Figure 4.24: Performance comparison of Neuro-Fuzzy based ACM with Fuzzy logic based ACM and threshold ACM

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, rain attenuation is computed using ITU-R rain attenuation model based on locally measured rain data. Then, mitigation of this rain attenuation using Neuro-Fuzzy based ACM system is performed. The performance of Neuro-Fussy based ACM systems in terms of spectral efficiency and BER using various coding rates and modulation schemes under AWGN channel was analyzed and compared to fixed and adaptive techniques. Based on the extensive study and analysis carried out in this research work, the following conclusions are drawn:

- The SNR at the receiving end of the link between Jimma and Muja is 32.5 dB in the clear sky(non-rain time)condition.On the other hand, for rain rate above 130mm/hr ,there will be a total link outage.
- the rain rate and SNR at the receiving end is inversely related.Thus,enhancing the data rate or sustaining the link availability of a wireless system using the received SNR level means mitigating rain induced attenuation.
- The BER performance is improved by using FEC coding rate. However, selecting lower code rate can reduce spectral efficiency.
- During good quality of channel (non- rain time), higher coding and modulation orders such as 256 QAM,512 QAM, 1024 QAM with coding rate $\frac{2}{3}$ and $\frac{3}{4}$, can be used to improve data rate. Since the frequency spectrum is limited, ACM is applied to efficiently utilize the available bandwidth.
- During bad channel conditionrainy time, the more robust modulation schemes like 4QAM, 8QAM and 16QAM (lower modulation order QAM) is better in sustaining link availability. For instance,in rainy condition it is better to use a lower order modulation with a lower

coding rate. At a rain rate above 105mm/hr, the signal to noise ratio level is reduced to around 6dB. This implies that using high order modulation scheme ,which demands high SNR, such as 128QAM,256QAM,512QAM AND 1024QAM along with high code rate like 2/3 and 3/4 result in link reliability reduction.

- ACM has shown better system performance in terms of spectral efficiency and achieving a target BER compared to non-adaptive techniques.
- Comparison of fuzzy based ACM and ANFIS based ACM illustrates that the adaptability performance of ANFIS-based adaptive coding and modulation system is more efficient. It is shown that using soft computing techniques as a decision-making mechanism gives a better result in adaptation of the channel condition compared to the traditional ACM system.
- Base on simulation result analysis, Neuro-Fuzzy based adaptive coded modulation system showed a smooth and high adaptation capability than the fuzzy based ACM and the switching threshold ACM.

5.2 Recommendations and Future Work

The designed scheme suits a single frequency carrier system in which the communication link supports a one user down-link or up- link system. Since the study is based on a rain data collected from Jimma University, Ethiopia, the result can be used as an input in microwave and millimetric band radio link design in this area. Investigating multicarrier channel transmission like OFDM using Neuro-Fuzzy based ACM is my future plan.In this future plan, studying of more link sites are included to cover wide area.

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APPENDICES

MATLAB Programme Codes

Matlab code for adaptive coding and modulation for OFDM systems with 1/4, 1/3 and 1/2 coding rate

```
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This code is prepared by Eyob Mersha
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% School of Electrical Engineering and Computing
% Adama Science and Technology University
% June,2017
% Simulation code of adaptive coding and modulation for with coding rate 1/2 and modulation order 4QAM, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, and 1024QAM.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc;
clear all;
close all;
for M =[2 4 8 16 32 64 128 256 512 1024] % Size of signal constellation;
k = log2(M); % Number of bits per symbol
numSamplesPerSymbol = k;
codeRate =1/2;
niter=1;
% Setting number of bits to process for each QAM scheme
switch(M)
case 2
numBits =1e7;
```

```
case 4
numBits =1e7;
case 8
numBits =0.999999e7;
case 16
numBits =1e7;
case 32
numBits =1e7;
case 64
numBits =0.999996e7;
case 128
numBits =0.999992e7 ;
case 256
numBits =1e7;
case 512
numBits =0.999999e7;
case 1024
numBits =1e67;
end % end of number of bit selection that are exact multiple of the modulation order code pair
%%%%%%%%%%AWGN Channel%%%%%%%%%%%%%%%%%
EbNo = [0:35];
SNR =EbNo + 10*log10(k*codeRate)-10*log10(numSamplesPerSymbol);
% or SNR =EbNo + 10*log10(codeRate) noiseVar =10.^(-SNR/10);
BER=zeros(1,length(SNR));
for snr=1:length(SNR)
total_ber=0; % bit error rate initialization
for runs=1:niter
rng default % Use default random number generator
dataIn = randi([0 1], numBits, 1); %  Generate vector of binary data
constlen=3; % length of constraint
codegen=[6 5 7]; % polynomial of the encoder
```

```
tPoly = poly2trellis(constlen,codegen);
% polytrellis structure
dataEnc = convenc(dataIn, tPoly);
%%%%%%%%%%Modulate Data%  %%%%%%%%%%%%%%%%%%%%%
%Apply QAM modulation
txSignal = qammod(dataEnc,M,'InputType','bit','UnitAveragePower',true);
%% Pass the filtered signal through an AWGN channel
rxSignal = awgn(txSignal, snr, 'measured');
% Receive and Demodulate the Signal
rxDataSoft = qamdemod(rxSignal,M,'OutputType','approxllr','UnitAveragePower',true,'NoiseVariance',noiseV
%%%%%%%Viterbi Decoding %%%%%%%%%
traceBack = 16; %Traceback length for decoding
dataout = vitdec(rxDataSoft,tPoly,traceBack,'cont','unquant');
%%%%%%%%%%%%%BER Calculation%%%%%%%%%%%%%%%%%%%%
decDelay =traceBack; % Decoder delay, in bits
 [numErrors, ber] = biterr(dataIn(1:end-decDelay),dataout(decDelay+1:end));
total_ber=total_ber+ber;
end % number of niter loop
% compute average BER
BER(snr) = total_ber/(niter);
end % snr loop
%  %%%%%% Plot graphs%%%%%%%%%
if M==2
semilogy(EbNo(1:end),BER(1:end),'-b*','lineWidth',1.2, 'MarkerSize',7);
elseif M==4
semilogy(EbNo(1:end),BER(1:end),'-rv','lineWidth',1.2, 'MarkerSize',7);
elseif M==8
semilogy(EbNo(1:end),BER(1:end),'-ks','lineWidth',1.2, 'MarkerSize',7);
elseif M==16
semilogy(EbNo(1:end),BER(1:end),'-m+','lineWidth',1.2, 'MarkerSize',7);
elseif M==32
```

```
semilogy(EbNo(1:end),BER(1:end),'-cd','lineWidth',1.2, 'MarkerSize',7);
elseif M==64
semilogy(EbNo(1:end),BER(1:end),'-g>','lineWidth',1.2, 'MarkerSize',7);
elseif M==128
semilogy(EbNo(1:end),BER(1:end),'-ms','lineWidth',1.2, 'MarkerSize',7);
elseif M==256
semilogy(EbNo(1:end),BER(1:end),'-kd','lineWidth',1.2, 'MarkerSize',7);
elseif M ==512
semilogy(EbNo(1:end),BER(1:end),'-r<','lineWidth',1.2, 'MarkerSize',7);
else
semilogy(EbNo(1:end),BER(1:end),'-b*','lineWidth',1.2, 'MarkerSize',7);
end
axis([0 35 10^-7 1 ])
legend('2QAM','4QAM','8QAM','16QAM','32QAM', . . .,
'64QAM','128QAM','256QAM','512QAM','1024QAM');
grid on
hold on
xlabel('Signal-to-Noise Ratio(dB)')
ylabel('Bit Error Rate')
title('MQAM With Coding Rate 1/2')
```

MATLAB code for ploting particular modulation scheme with a particular coding rate.In this case the code for 1024QAM along with coding rate 1/4 is presented.

```
clc;
clear all;
close all;
M =1024; % Size of signal constellation
k = log2(M); % Number of bits per symbol
numSamplesPerSymbol = k;
codeRate = 1/4;
```

niter=5; % number of times BER calculation is iterated

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

EbNo1024 = [0:35];

SNR =EbNo1024 + 10*log10(k*codeRate)-10*log10(numSamplesPerSymbol);

noiseVar= $10.^{(-SNR/10)}$;

BER1024=zeros(1,length(SNR));

for snr=1:length(SNR)

$total_{ber}$=0; % number of bits received in error initialization

for runs=1:niter

numBits =1e7; % Number of bits to process

rng default % Use default random number generator

dataIn = randi([0 1], numBits, 1); % Generate vector of binary data

constlen=3; % constraint length of the convolutional encoder

codegen=[6 5 7 4]; % polynomial generator

tPoly = poly2trellis(constlen,codegen);

%%%%%Encode the input data using the previously created trellis %%%%%%%%%%

dataEnc = convenc(dataIn, tPoly);

%%%%%%%% Modulate Data%%%%%%%%%%%%% %

%%%%%% Apply QAM modulation.

txSignal = qammod(dataEnc,M,'InputType','bit','UnitAveragePower',true);

%%%%%% AWGN CHANNEL %%%%%%%

%%%%%% Pass the modulated signal through an AWGN channel.

rxSignal = awgn(txSignal, snr, 'measured');

%%%%%% Receive and Demodulate Signal

rxDataSoft = qamdemod(rxSignal,M,'OutputType','approxllr','UnitAveragePower',true,'NoiseVariance',noiseV

%%%%%%%%% Viterbi Decoding %%%%%%%%%%%5%

traceBack = 16; %Traceback length for decoding

dataout = vitdec(rxDataSoft,tPoly,traceBack,'cont','unquant');

%%%%%%%%%%%%%%%%BER Calculation %%%%%%%%%%%%%%%%%%%

decDelay =traceBack; %Decoder delay, in bits

$[numErrors, ber]$ = biterr(dataIn(1:end-decDelay),dataout(decDelay+1:end));

$total_{ber} = total_{ber}$+ber;

end % number of niter loop

%%%%%%compute average BER

BER1024(snr)=$total_{ber}$/(niter);

end % snr loop

%%%%%%%%%% Plot graphs %%%%%%%%%%% semilogy(EbNo1024(1:end),BER1024(1:end),'-b*','lineWidth',1.2, 'MarkerSize',7);

axis([0 35 10^{-7} 1])

legend('1024QAM');

grid on

xlabel('Signal-to-Noise Ratio(dB)')

ylabel('Bit Error Rate')

title('SNR vs BER')

format long

$[EbNo1024, BER1024, BUTTON]$=ginput(12) % code used to extract the value of BER for each target BER value of $10_{-2}, 10_{-3}, 10_{-4}, 10_{-5} and 10_{-6}$

Matlab code for BER comparison for 256QAM with different coding rates and 1/2 coding rate

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

M = 256; % Size of signal constellation

k = log2(M); % Number of bits per symbol

numSamplesPerSymbol = k;

niter=3;

$color_{vec1}$= ['b-','r-','k-','r-','g-', 'k-','r-','b-'];

% Input the convolutional coding rate

$code_{rate}$=input('input the coding rate(1/4, 1/3, 1/2, 2/3,3/4)');

if ($code_{rate}$ =1/4 && $code_{rate}$ = 1/3 &&

$code_{rate}$ =1/2 && $code_{rate}$ =2/3 &&

@$code_{rate}$ =3/4)

error('Enter the correct coding rate')

end

%%%%%%%%%%%%%AWGN Channel %%%%%%%%%%%%%%%%%%%%

EbNo = [0:35]; % specify the range of signal-to-noise ratio in dB

SNR =EbNo + 10*log10(k*codeRate)-10*log10(numSamplesPerSymbol);

$noiseVar = 10.^{(-SNR/10)}$;

BER=zeros(1,length(SNR));

for snr=1:length(SNR)

$total_{ber}$ =0;

for runs=1:niter

numBits =1e7; % Number of bits to process

rng default % Use default random number generator

dataIn = randi([0 1], numBits, 1); % Generate vector of binary data

% %%%%% Convolutionally encoding data%%%%%%%%%

if $code_{rate}$ ==1/4

constlen=3; % constraint length

codegen=[6 5 7 4]; % polynomial of the encoder

elseif $code_{rate}$ ==1/3

constlen=3;

codegen=[6 5 7];

elseif $code_{rate}$ == 1/2

constlen=3;

codegen=[6 7];

elseif $code_{rate}$ ==2/3

constlen=[3 3];

codegen=[7 6 7 ; 7 4 5];

elseif $code_{rate}$ ==3/4

constlen=[3 3 3];

codegen=[7 6 4 5;3 5 7 6;5 4 7 3];

else

constlen=3;

codegen=7;

```
end
% % polynomial to trellis structure
tPoly = poly2trellis(constlen, codegen);
%%% Encode the input data using the previously created trellis%%%
dataEnc = convenc(dataIn, tPoly);
% %% Modulate Data%%%%%%%
%%%%%Apply QAM modulation
txSignal = qammod(dataEnc,M,'InputType','bit','UnitAveragePower',true);
%%%%%Pass the filtered signal through an AWGN channel % %%%%
rxSignal = awgn(txSignal, snr, 'measured');
% %%% Receive and Demodulate Signal%%%%%
rxDataSoft = qamdemod(rxSignal,M,'OutputType','approxllr','UnitAveragePower',true,...
'NoiseVariance',noiseVar);
%%%%%%% Viterbi Decoding
traceBack = 16; % Traceback length for decoding
dataout = vitdec(rxDataSoft,tPoly,traceBack,'cont','unquant');
%%%%%% BER Calculation%%%%%%%%%%%%%%
%%% setting the tracback length
if code_rate < 2/3
decDelay=traceBack;
elseif code_rate ==2/3
decDelay = 2*traceBack; % Decoder delay, in bits
else
decDelay = 3*traceBack;
end
 [numErrors, ber] = biterr(dataIn(1:end-decDelay),dataout(decDelay+1:end));
total_ber = total_ber+ber;
end % number of niter loop
%%%%%%% compute average BER%%%%%%%%% BER(snr)=total_ber/(niter);
end % snr loop
%%%%%%%%%%%%% Plot graphs%%%%%%%%%%%%%%%%%%%5
```

semilogy(EbNo(1:end),BER(1:end),'-*','lineWidth',1.2, 'MarkerSize',7); axis([0 40 10^{-6} 1])
legend('1/4 code rate','1/3 code rate', '1/2 code rate','code rate 2/3','code rate 3/4','Uncoded msg');
grid on
hold on
xlabel('Signal-to-Noise Ratio(dB)')
ylabel('Bit Error Rate')
title('16QAM with different coding rate')

MATLAb code for BER performance data extraction

```
clear all;
close all;
clc;
h=openfig('S4QAM-13.fig');  % importing the BER performance plot for a particular Modulation code pair
h=findobj(gca,'Type','line');
x=get(h, 'Xdata');
y=get(h, 'Ydata');
A=[];
A(:,1)=x;
A(:,2)=y;
dlmwrite('data.txt',A,',');
```