

Coding Rates and MCS using Adaptive Modulation for WiMAX in OFDM Systems using GNU Radio

Lakshmi Boppana Chandana N. Amanchi and Ravi Kishore Kodali

Department of Electronics and Communication Engineering

National Institute of Technology, Warangal

Andhra Pradesh, India

Abstract-Various wireless technologies have been emerging with ever increasing demand for higher data rates along with low bit error rates (BER's). Adaptive modulation and coding (AMC) schemes, when incorporated into WiMAX helps the system to react dynamically to the channel variations thereby providing higher data rates and improve BER performance. Based on the channel state information, both the modulation and coding rates can be varied so as to achieve higher throughput and improve spectral efficiency. This work proposes an efficient adaptive modulation coding technique, which maximizes the throughput, while maintaining a target BER. It proposes to select a particular modulation coding scheme along with the corresponding coding rates based on the given threshold. The parameter values, such as SNR, BER, CINR, BLER channel attenuation factor, are accepted and then the modulation schemes with an appropriate coding rate are selected for the operation of a OFDM system in GNU Radio.

Keywords: OFDM, BER, WiMAX, SDR.

I. INTRODUCTION

The open source software, GNU Radio is used in the implementation of Software defined radio (SDR). In SDR, the signal processing blocks are implemented in software, instead of hardware [3]. For real time applications, a peripheral called Universal Software Radio Peripheral(USRP), is used. Using this USRP, we can receive and transmit real time signals. In between the transmitter and receiver, signal processing can be performed, using the GNU Radio companion software.

In present days, modern communication systems must support information transfer at high data rates, enabling high speed multimedia services and high quality information transfer. Engineering wireless standards, such as, WiMAX support high data rates and are a viable solution for this problem [9]. Orthogonal frequency division multiplexing (OFDM) using IEEE 802.16 standard achieves these high data rates. The usage of OFDM in WiMAX, eliminates both inter-symbol interference (ISI) and inter-carrier interference effects in multipath transmission.

OFDM is a method of digital modulation, in which a single transmission signal is divided into several narrowband signals [1]. These signals are transmitted using a carrier, which are orthogonal to each other. The advantage of OFDM over a single carrier systems is its ability to tolerate the adverse and

harsh channel conditions. OFDM also reduces the fading effect and improves the data transmission rate.

Orthogonal frequency division multiple access (OFDMA) is a multiple access technique, which involves the use of OFDM digital modulation for transmission and reception. The advantage of this multiple access is its ability to endure multipath interference.

In modern communication systems, the use of Adaptive modulation and coding (AMC) techniques enables the system to achieve high spectral efficiency. The core idea of AMC is to change dynamically the modulation and coding schemes based on the channel statistics so as to improve overall spectral efficiency. The receiver decides the Modulation and coding scheme (MCS) to be used on channel state information and fed back to the transmitter. Many AMC techniques, link adaptation techniques have been proposed in the literature. These schemes include rate and power adaptation. The power adaptation schemes use water filling strategy based on the channel state information.

In this work, two AMC techniques are discussed. The two methods aim at switching the MCS based on target BER and maximum throughput approach [1]. In the target BER technique, the modulation and coding schemes are selected with an objective to maintain the BER below a target value, making use of a set of threshold values, the estimated SNR is partitioned into a set of regions. Each region is associated with a different MCS, such that, the BER is maintained below a target value. An alternative AMC technique is to switch the MCS in order to maximize the throughput. In maximum throughput, less emphasis is given to maintain a specified BER.

Channel coding is a method to make the transmitted signals less susceptible to errors. It involves addition of extra bits, normally called as parity bits. It also involves scrambling, forward error correction (FEC), and interleaving. This work makes use of convolution coding technique for FEC. Two different code rates of $\frac{1}{2}$ and $\frac{3}{4}$ have been discussed. The rest of the paper is organized as follows: Section II explains OFDM, section III gives OFDMA-Modulation switching, section IV provides convolutional coding, section presents the selector block, section VI discusses simulation results and finally section VII concludes the paper.

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

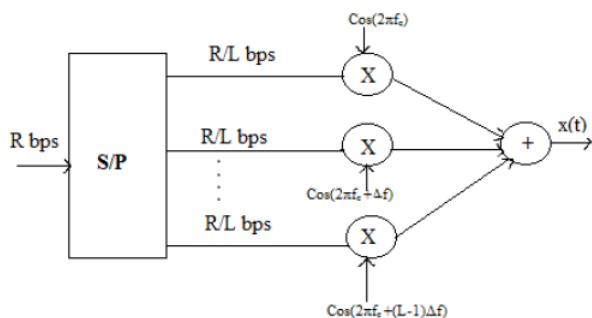


Fig. 1: A basic multi-carrier system

OFDM is a combination of modulation and multiplexing. Various independent signals produced by different sources are multiplexed. As shown in Figure 1, multi-carrier modulation divides the wideband high data rate R bps incoming data stream and with a passband bandwidth R/L , each of which is then transmitted over a different orthogonal-frequency sub-channel.

The data rate of WiMAX [9] is given in equation (1).

$$R = \frac{B \cdot L_d \times \log_2(M)}{L(1+G)} \quad (1)$$

In OFDM-WiMAX PHY layer, if 16-QAM is used as modulation scheme, then the data rate is given in equation (2).

$$R = \frac{10^7 \text{ MHz} \times 768 \times \log_2(16)}{(1024)(1.125)} = 24 \text{ Mbps} \quad (2)$$

Each of the data-carrying sub-carriers of bandwidth $\frac{B}{L}$ carries bits of data. An additional overhead penalty of $(1+G)$ is incurred for the cyclic prefix, due to its information redundancy and the transmission of actual data symbols is sacrificed.

III. OFDMA- MODULATION SWITCHING

AMC systems making use of capabilities of the OFDMA are considered. The modulation order and coding rate of each symbol, c_k , associated with the k^{th} sub-carrier, where $0 \leq k \leq 1023$, could be modified depending on the physical channel state and the MCS [6] is changed accordingly for all the sub-carriers of the slot. The selection of the modulation is based on the channel parameters. In this work, the channel state approach is considered as Adaptive Modulation techniques [8].

A. Channel state technique

The following two algorithms based on the channel state approach are given: i) Maximum throughput (MT) and ii) Target Block error rate (TBLE). Five thresholds are used to characterise both the algorithms. The same modulation and coding scheme (MCS) is used until the parameter under

measurement (SNR, BER, throughput or channel attenuation factor) crosses a threshold [7]. This work considers the channel attenuation factor as the channel state parameter.

While the MT algorithm maximizes the system throughput without target block error probability constraints, the TBLE algorithm attempts to achieve certain target block error rate due to the required QoS. The TBLE can be the same for each of the mean SNR averaged over the frame, or the target can be varied.

1) *MT algorithm*: The thresholds required for the MCS selection for the MT approach are shown in Table I. The MT algorithm aspires to maximize the overall link throughput by choosing for each SNR value, the MCS that allows the maximum throughput. Hence, the transmission efficiency is enhanced but the performance in terms of error rate could be degraded, since no constraint on the maximum acceptable error probability is introduced. The objective is to choose, for each frame and SNR value, the modulation order that maximizes the total throughput. The final result is that the most efficient scheme in terms of throughput for each value is selected. Based on the throughput comparison of the transmission schemes, the thresholds can be determined. The classical throughput equation given in [10] is changed as required by the slot structure of the system. The throughput (η) is a function of the channel attenuation factor α and used MCS for a fixed mean square SNR is given by equation (3) [1].

$$\eta = \frac{4 \times (1 - P_{block}(\alpha, \widehat{SNR}, M, R_c)) N_c \times N_{sd} \log_2 M \cdot R_c}{4 \times T_f} \quad (3)$$

where M is modulation order = 4, 16, 64, P_{block} is the block error probability related to each pair of modulation coding rate, N_c is the number of sub-carriers per user, N_{sd} is number of OFDM symbols in OFDMA subframe of the downlink, R_c is adopted coding rate and the OFDMA frame duration is denoted by T_f . p_{sym} , the symbol error probability in a Rayleigh channel is given by equation (4) [1].

$$P_{sym}(\widehat{SNR}, \alpha, M) = \frac{4(\sqrt{M}-1)}{\sqrt{M}} \times Q\left(\sqrt{\frac{3 \times \widehat{SNR} \times \alpha^2}{M-1}}\right) - \left[\frac{2\sqrt{M}-1}{\sqrt{M}} Q\left(\sqrt{\frac{3 \times \widehat{SNR} \times \alpha^2}{M-1}}\right)\right] \quad (4)$$

As can be noticed that $p_{b_{MQAM}}$ and $p_{sym_{MQAM}}$ are functions of M , modulation order and \widehat{SNR} [11].

2) *TBLE technique*: Table II provides the thresholds required for the MCS selection in this technique. In this approach, the error rate is kept less than a target limit, thereby ensuring a fixed QoS level in terms of P_{block} [1]. This approach is more suited in services requiring strict adherence to certain maximum error rate value. Different values of the target BLE have their correspondence with different system performances. For a given SNR, the BLE as a function of α is derived. Consequently, there are five definite thresholds corresponding to state transitions enabling modulation switch-

TABLE I: MCS selection for the MT approach [1]

Parameter value	Modulation scheme
$\alpha < 0.09$	QPSK $\frac{1}{2}$
$0.09 < \alpha \leq 0.2$	QPSK $\frac{3}{4}$
$0.2 < \alpha \leq 0.33$	16QAM $\frac{1}{2}$
$0.33 < \alpha \leq 0.51$	16QAM $\frac{3}{4}$
$0.51 < \alpha \leq 0.57$	64QAM $\frac{1}{2}$
$0.57 < \alpha$	64QAM $\frac{3}{4}$

ing. For a given \widehat{SNR} and MCS parameters, the values of α provide the TBLER.

TABLE II: MCS selection for the TBLER approach [1]

Parameter Value	Modulation Scheme
$\alpha < 0.46$	QPSK $\frac{1}{2}$
$0.46 < \alpha \leq 0.65$	QPSK $\frac{3}{4}$
$0.65 < \alpha \leq 0.95$	16QAM $\frac{1}{2}$
$0.95 < \alpha \leq 1.38$	16QAM $\frac{3}{4}$
$1.38 < \alpha \leq 1.95$	64QAM $\frac{1}{2}$
$1.95 < \alpha$	64QAM $\frac{3}{4}$

IV. CONVOLUTION CODING

Convolution codes are used in applications that require good performance and low implementation cost. They operate on data stream. It involves addition of parity bits to reduce the susceptibility to errors in the transmitted signals. Error correcting codes are necessary in modern communication systems in order to recover the transmitted signal with low bit error rate. Convolution coding is incorporated into the *WiMAX* system for reliable data transfer and *WiMAX* supports coding rates of $\frac{1}{2}$ and $\frac{3}{4}$ for encoding the data. In AMC technique, coding rate is also switched along with modulation technique. Switching of the coding rate technique according to the channel conditions enables reliable data transmission. Under unreliable channel conditions, the coding rate $\frac{1}{2}$, is used for encoding the data, while in reliable channel conditions coding rate $\frac{3}{4}$ is used. Convolution codes are commonly specified by three parameters, (n,k,m), n = number of output bits, k = number of input bits, m = number of memory registers.

The quantity $\frac{k}{n}$ is called code rate. It measures efficiency of the code. The range of k and n is from 1 to 8 and m ranges from 2 to 10. Thus, code rate ranges from $\frac{1}{8}$ to $\frac{7}{8}$. In *WiMAX*, we use code rates of $\frac{1}{2}$ and $\frac{3}{4}$ according to the IEEE 802.11 standard. The quantity L is called the constraint length of the code and is defined by $L = k \times (m - 1)$. The code rate of $\frac{1}{2}$ is generated with a constraint length of 7. The code rate of

$\frac{3}{4}$ is generated by puncturing the input data. The puncturing matrix for coding rate of $\frac{3}{4}$ is $[(1\ 0\ 1)(1\ 1\ 0)]$. So, in order to get a code rate of $\frac{3}{4}$, the data must be first encoded using a basic encoder and then transmit every first and third bit in the first branch and every first and second bit in the second branch. For the purpose of decoding, Viterbi decoder is used.

V. SELECTOR BLOCK

The selector block has been developed in Python scripting language [4]. The same block has also been integrated with the basic OFDM system in GNU Radio companion software that includes an encoder-decoder block for deciding the coding rate. It selects the modulation scheme of different coding rates according to the approaches of Rayleigh channel fading [10]. The approaches, as discussed before, are Maximum throughput approach and target BLER approach. This block facilitates automation in selection of the modulation schemes of different code rates being used in OFDM. Thus, there is no further need to manually select the modulation scheme and then run the .grc file in GNU Radio companion software. We can directly run the program in which the block has already been integrated and then according to the parameter, it automatically selects the modulation scheme and gives us the modulated output and the same is illustrated using Figure 2.

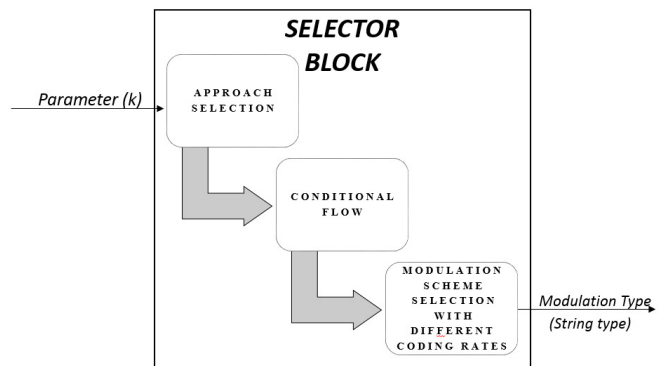


Fig. 2: Selector Block

After the execution of the above conditional flow statements, a modulation scheme with appropriate coding rate would have been selected and the same can be used in the OFDM system

VI. SIMULATION RESULTS

The required OFDM specifications for *WiMAX* setup are shown Table III. OFDM can be implemented by using an open source software GNU Radio companion as shown in Figure 3. OFDM parameters are configured according to Table III and executed for 64QAM $\frac{1}{2}$ is shown in Figure 4. In this paper, a selector block has been created using Python script for the automatic selection of modulation scheme with different coding rates in OFDM block.

The modulation coding schemes are selected according to the MT approach are reported in Table I. As for the MT technique, whenever a dissimilar propagation environment is conceived, it is straightforward to note that, due to different

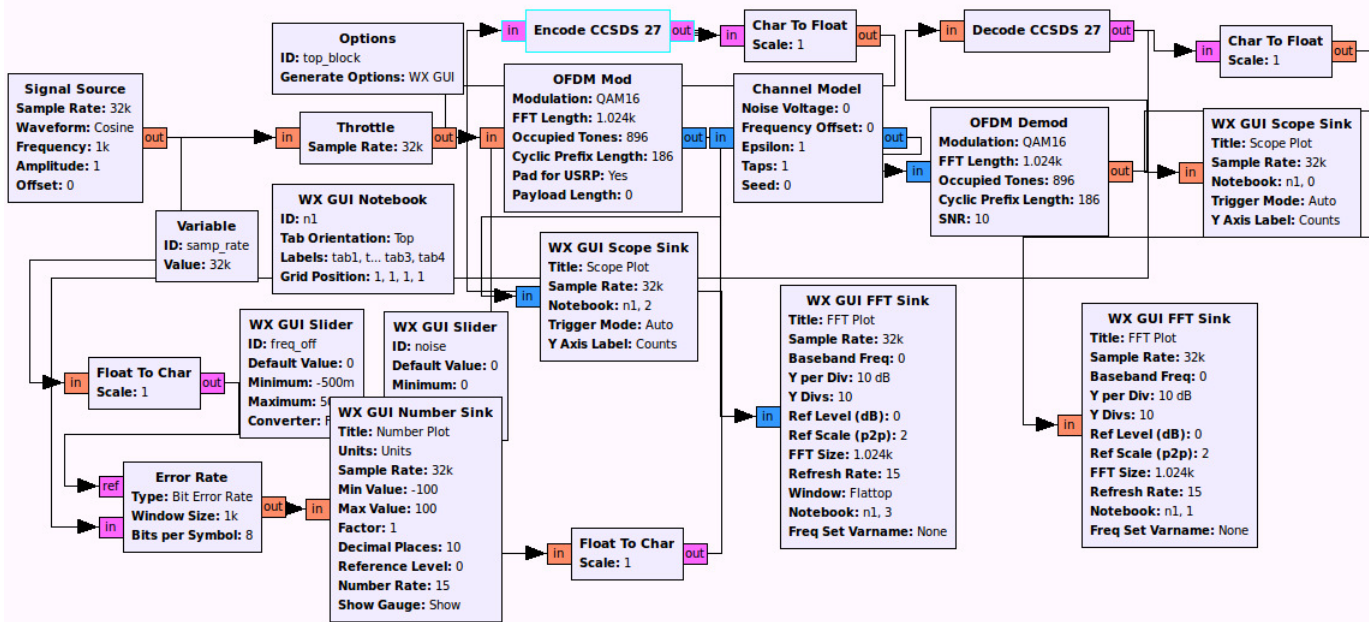


Fig. 3: GNU Radio schematic for 64 QAM $\frac{1}{2}$ implementation

TABLE III: Simulation parameters defined

Parameters	Values
FFT size (NFFT)	1024
Occupied Tones	840
Sampling rate	10.66667 M
Center Frequency	2.48 GHz
Convolutional Code	$\frac{1}{2}$
Cyclic Prefix length	184
Useful symbol duration	91.43 μ s
Carrier spacing ($\frac{1}{T_u}$)	10.94 KHz
Guard time ($T_g = \frac{T_u}{4}$)	11.43 μ s
OFDM symbol duration	102.86 μ s
Digital Modulations	BPSK, QPSK, 16QAM, 64QAM

performance in terms of BLER, the thresholds have different values. The resulting MCS's are related to switching thresholds according to the TBLE approach as shown in Table II. The specific modulation scheme has been selected based on two approaches.

The results have been verified for their BER values. The BER obtained for the coding rate of $\frac{1}{2}$ is 0.6138883809 units and the BER obtained for the coding rate of $\frac{3}{4}$ is 0.7769923210 units. The above results for the bit error rate values also proves that with an increase in coding rate results in improved BER value.

Figure 8 shows a plot of BER vs. SNR for various modulation and coding techniques. Various modulation techniques

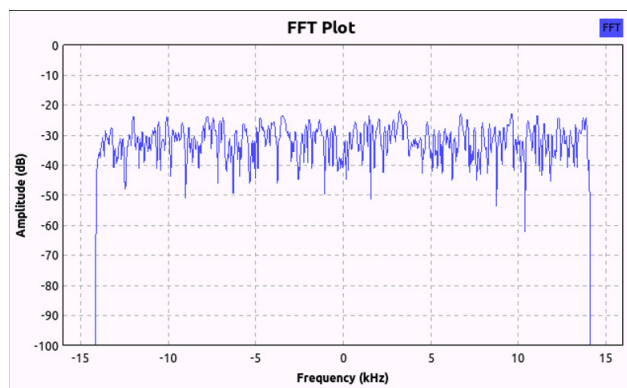


Fig. 4: 64 QAM $\frac{1}{2}$ output obtained by manual selection using Maximum throughput approach

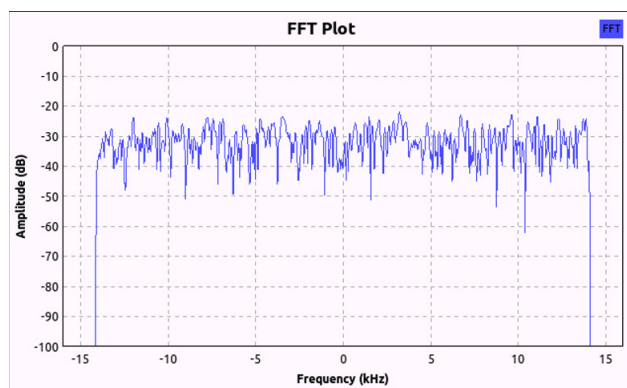


Fig. 5: 64 QAM $\frac{1}{2}$ output obtained by automatic switching using Maximum throughput approach

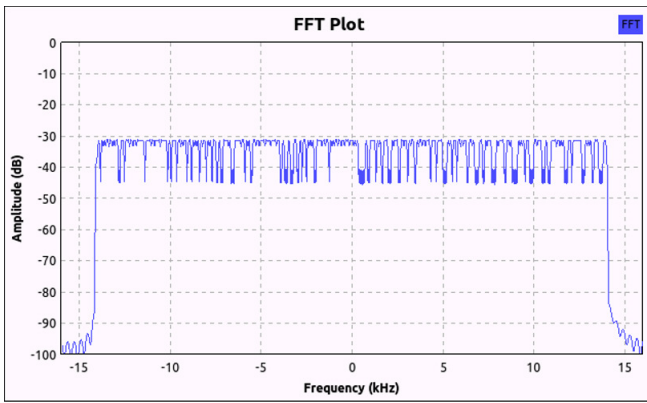


Fig. 6: 64QAM $\frac{3}{4}$ output by manual selection using TBLE approach

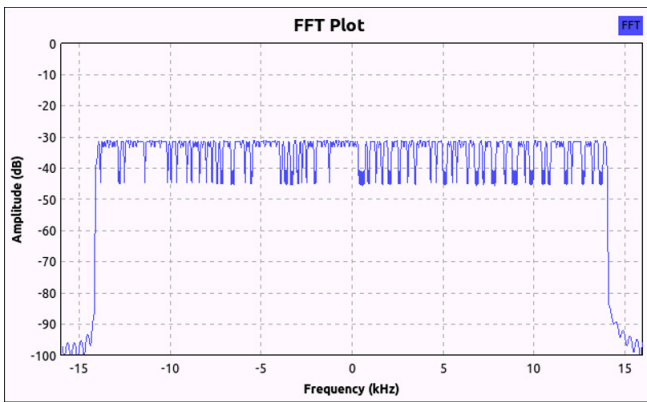


Fig. 7: 64QAM $\frac{3}{4}$ output by automatic switching using TBLE approach

QPSK, 16-QAM, 64-QAM, are used for simulation. The data is first encoded using coding rates $\frac{1}{2}$ and $\frac{3}{4}$ and then transmitted using a suitable modulation technique. From Figure 8, it can be inferred that the BER rate decreases with an increase in SNR. Also the BER performance of QPSK is better than that of the QAM. As the order of modulation increases the BER performance decreases. Thus in a very noisy channel QPSK modulation needs to be used. In a channel with low noise a modulation with higher order can be used. From Figure 8, it can be observed that the coding rate $\frac{1}{2}$ has a better BER performance than the coding rate $\frac{3}{4}$. So in a channel prone to high interference and noise coding rate $\frac{1}{2}$ needs to be used in order to recover the transmitted signal at the receiver with minimum error. In a channel with less interference effects and low noise the coding rate $\frac{3}{4}$ is suitable for encoding the data before transmission.

So in AMC we combine different modulation and coding schemes in order to achieve better BER performance. Switching the MCS according to the channel conditions increases the BER performance and ensures reliable data transmission with high data rates. Combining the modulation and coding technique it is observed that QPSK has the best BER performance among the MCS used. In traditional communication systems

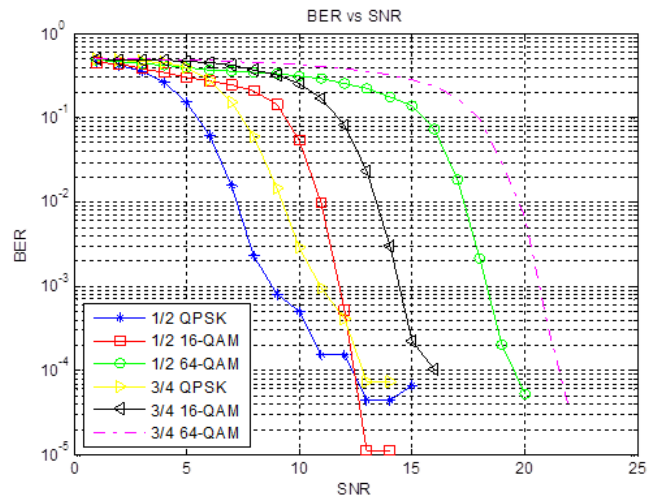


Fig. 8: BER vs. SNR characteristics of different MCS schemes

the system was designed for worst case channel conditions. Designing the system according to the worst case channel conditions deteriorates system performance. Thus AMC is introduced in system design to increase system performance. So in AMC the MCS is switched according to the channel conditions thus improving the system performance and leads to optimum utilization of communication resources.

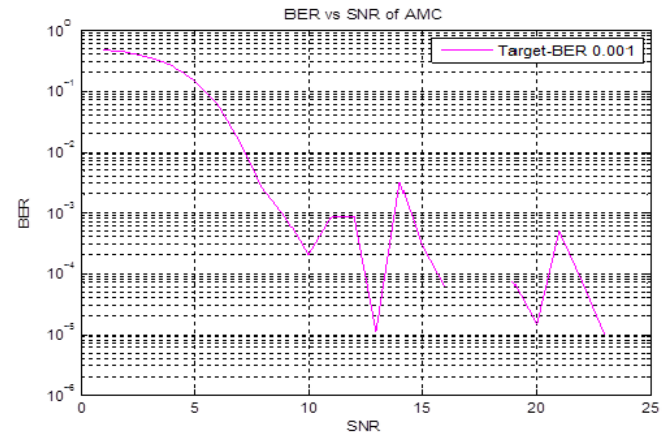


Fig. 9: Performance of Target BER of 0.001

The MCS is switched according to the channel conditions in order to maintain a BER threshold of 0.001 as shown in Figure 9. For different SNR values the MCS is switched to obtain a BER below the threshold level. This technique of limiting the BER to a certain threshold is called Target BER technique. Here much emphasis is laid on limiting the BER and there is a slight compromise in the throughput of the system. This is a design trade off and AMC tries to achieve a balance between throughput and BER performance of the system. At low SNR values, QPSK $\frac{1}{2}$ is used for transmission. At high SNR, where there is low noise, 64-QAM with coding rate $\frac{3}{4}$ is used. For SNR ranging from 10dB to 11dB QPSK $\frac{3}{4}$ is used and for SNR ranging from 12 to 15dB 16-QAM with coding rate $\frac{1}{2}$

is used for transmission. 16-QAM with coding rate $\frac{3}{4}$ is used to transmit the signal for SNR values ranging from 15dB to 20dB [11]. For SNR values greater than 20dB 64-QAM with coding rate of $\frac{3}{4}$ is used. The partitioning of the SNR values into several regions depends upon the threshold BER level. For each region a different MCS is used to limit the BER. To obtain a different threshold of BER partitioning of the SNR values must be done again in order to limit the overall BER to the desired threshold.

Based on the results, it can be stated that the specific system requirements are used while selecting the best adaptive algorithm. The MT technique is more suited in applications having strict throughput requirements. The TBLEER technique is more suitable in applications, where in order to achieve the required QoS, target error rate needs to be chosen. In the TBLEER technique, the target value can be altered, whenever a specific application QoS requirement is to be met.

VII. CONCLUSIONS

This work has presented the use of different coding rates along with the modulation switching of the modulation schemes. It also discussed the usage of adaptive modulation scheme in OFDMA systems. The selector block has been developed in python scripting language. It automatically selects the modulation schemes with the appropriate coding rate based on the two approaches discussed in channel estimation techniques. It takes a parameter as an input and based on the value of that parameter, it selects the scheme. The results obtained from the selector block have been compared and verified with the standard results. Whichever, condition gets satisfied, the corresponding modulation scheme is selected and the OFDM system is executed.

In this paper, the adaptive modulation and coding issues for a WiMAX system have been considered. The BER performance and throughput characteristics are used as a measure for AMC performance and investigated the technique of Target BER for AMC schemes by plotting BER vs. SNR characteristics.

From simulations, one can see that, at lower SNR value the QPSK modulation with $\frac{1}{2}$ convolutional coding modulation is preferred over others in terms of BER because it gives the lowest BER but the throughput or spectral efficiency is very low. Also, the throughput of 64 QAM with $\frac{3}{4}$ convolutional coding is higher than other MCS but experiencing highest BER.

We can infer that the spectral efficiency of AMC scheme with target BER 0.01 is higher than that of AMC scheme with target BER 0.001. So we can conclude that there is a trade-off between BER performance and spectral efficiency.

REFERENCES

- [1] Fantacci, Romano and Marabissi, Dania and Tarchi, Daniele and Habib, Ibrahim, "Adaptive modulation and coding techniques for OFDMA systems," *Communications Letters, IEEE*, pages 4876–4883,2009.
- [2] Andrews,Keller, Thomas and Hanzo, Lajos (2000). "Adaptive modulation techniques for duplex OFDM transmission" *Vehicular Technology, IEEE Transactions on* vol. 49 pages 1893 - 1906

- [3] Chen, Chi-Yuan and Tseng, Fan-Hsun and Chang, Kai-Di and Chao, Han-Chieh and Chen, Jiann-Liang and others, "Reconfigurable software defined radio and its applications" *Tamkang Journal of Science and Engineering* vol 13, 2010
- [4] Dobesova, Zdena,"Programming language python for data processing" *Electrical and Control Engineering (ICECE), 2011 International Conference*,pages 4866–4869, 2011.
- [5] GNU Radio Trac, <http://gnuradio.org/trac/wiki>.
- [6] Popescu, SO and Budura, G and Gontean, AS, "Review of PSK and QAM Digital modulation techniques on FPGA," *Computational Cybernetics and Technical Informatics (ICCC-CONTI), 2010 International Joint Conference on*, pages 327 – 332,2012.
- [7] Goldfeld, Lev and Lyandres, Vladimir and Wulich, Dov, "Minimum BER power loading for OFDM in fading channel," *Communications, IEEE Transactions on*, vol 50, pages 1729–1733, 2002.
- [8] Tarhini, Chadi and Chahed, Tijani, "On capacity of OFDMA-based IEEE802. 16 WiMAX including Adaptive Modulation and Coding (AMC) and inter-cell interference," *Local & Metropolitan Area Networks, 2007. LANMAN 2007. 15th IEEE Workshop on*,pages 139–144,2007.
- [9] Andrews, Jeffrey G and Ghosh, Arunabha and Muhamed, Rias, "Fundamentals of WiMAX: understanding broadband wireless networking," *Prentice Hall PTR*,2007.
- [10] TProakis, John G and Manolakis, Dimitris G," *Digital communications*," *McGraw-hill New York*,vol 3,1995.
- [11] Takeda, Daisuke and Yuk, C CHOW and Strauch, Paul and Tsurumi, Hiroshi," Threshold controlling scheme for adaptive modulation and coding system," *IEICE transactions on communications*,vol 89, pages - 1598 - 1604 ,2006.