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# Channel Estimation/Equalization with Adaptive Modulation and Coding over Multipath Faded Channels for WiMAX

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***Abstract*****—**Different order modulations combined with different coding schemes, allow sending more bits per symbol, thus achieving higher throughputs and better spectral efficiencies. However, it must also be noted that when using a modulation technique such as 64-QAM with less overhead bits, better signal-to-noise ratios (SNRs) are needed to overcome any Inter symbol Interference (ISI) and maintain a certain bit error ratio (BER). The use of adaptive modulation allows wireless technologies to yielding higher throughputs while also covering long distances. The aim of this paper is to implement an Adaptive Modulation and Coding (AMC) features of the WiMAX PHY in MATLAB and to analyze the performance of the system in different channel conditions (AWGN, Rayleigh and Rician fading channel) with channel estimation and blind equalization. Simulation results have demonstrated that the increment in modulation order causes to increment in throughput and BER values. These results derived a trade-off among modulation order, FFT length, throughput, BER value and spectral efficiency. The BER changes gradually for AWGN channel and arbitrarily for Rayleigh and Rician fade channels.

***Keywords*****—**AMC, CSI, CMA, OFDM, OFDMA, WiMAX.

## I.INTRODUCTION

THE IEEE WiMAX/802.16 [1] is a promising technology for broadband wireless metropolitan area networks (WMANs) as it can provide high throughput over long distances and can support different qualities of services. WiMax/802.16 technology ensures broadband access for the last mile. It provides a wireless backhaul network that enables high speed Internet access to residential, small and medium business customers, as well as Internet access for WiFi hot spots and cellular base stations [2]. It supports both point-to-multipoint (P2MP) and multipoint-to-multipoint (mesh) modes.

The original WiMAX standard only catered for fixed and Nomadic services. It was reviewed to address full mobility applications, hence the mobile WiMAX standard, defined under the IEEE 802.16e specification.

Mobile WiMAX supports full mobility, nomadic and fixed systems. It addresses the following needs which may answer the question of closing the digital divide

- It is cost effective.
- It offers high data rates.
- It supports fixed, nomadic and mobile applications thereby converging the Fixed and mobile networks.
- It is easy to deploy and has flexible network architectures.
- It supports interoperability with other networks. It is aimed at being the first truly a global wireless broadband network

Orthogonal Frequency Division Multiplexing (OFDM) [3] is a special form of multi-carrier transmission technique in which a single high rate data stream is divided into multiple low rate data streams. In this way the symbol rate on each subchannel is greatly reduced, and hence the effect of intersymbol interference (ISI) due to channel dispersion in time caused by multipath delay spread is reduced. The use of adaptive modulation and coding (AMC) schemes in wireless communication systems is a topic widely considered and investigated in the recent literature [4]-[6]. In [4] the idea of combining the OFDM technique with adaptive modulation and coding is presented by showing the advantages in terms of overall throughput. Received signal-to-noise ratio (SNR) is applied to measure of the sub-channel state to choose a suitable code-rate for every subcarrier. Transmit power and modulation for each subcarrier is determined for reduction of the adaptive algorithm. LSE (least square error) [7] and MMSE (minimum mean square error) [8] channel estimators are accustomed to give randomly varying channel state information (CSI) [9] to the transmitter by way of a feedback. Channel equalization [10] is necessary to mitigate ISI in frequency selective channels. In blind equalization [10], the specified signal is unknown to the receiver, except for its probabilistic or statistical properties over some known alphabets. As both the channel and its input are unknown, the aim of blind equalization is to recuperate the unknown input sequence based solely on its probabilistic and statistical properties. The LMS algorithm [11] is effective at reducing mean square error (MSE) involving the equalizer output and the training sequence. When the signal eye is open, the equalizer is then switched to tracking mode that will be commonly referred to as decision-directed. The CMA Equalizer [12] is to equalize a linearly modulated baseband signal by way of a dispersive channel.

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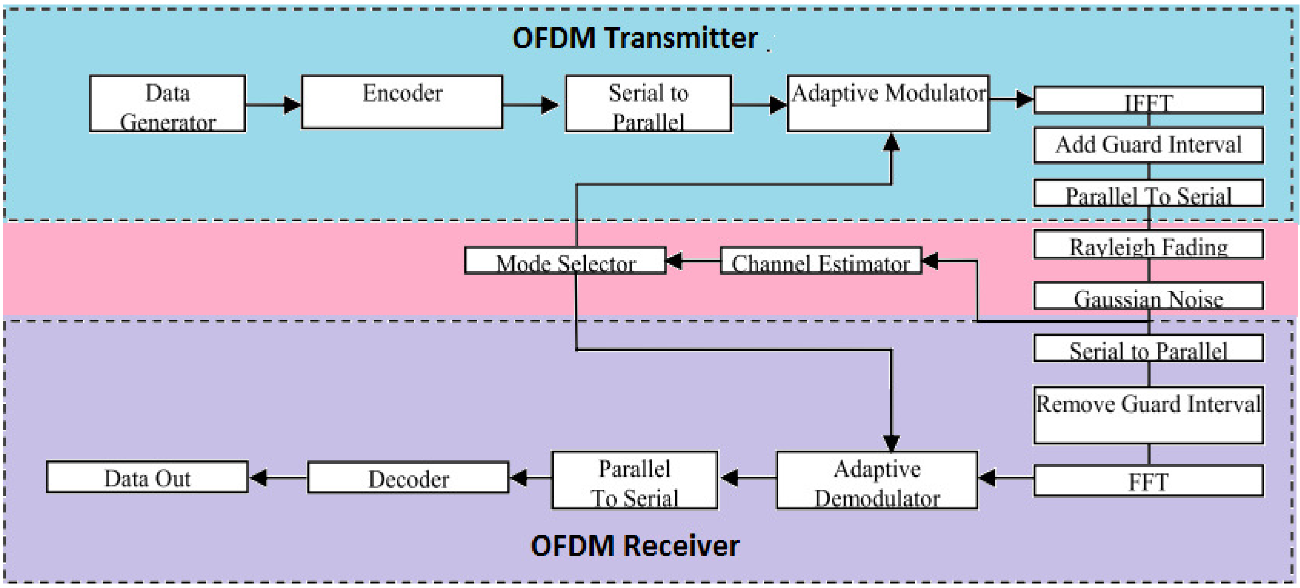

Fig. 1 A basic OFDM-AMC system model

## II. OFDM TRANSCEIVER SYSTEM MODEL

Recently, OFDM is employed in broadband wireless access due to its robustness against multipath, maximizes throughput, robustness against narrowband interference, establishes single frequency network, frequency diversity. In OFDM, the sub carriers are not separated but overlapped orthogonally. As a result of orthogonal overlapping, the bandwidth is significantly much more efficiently saved than in the classical multicarrier systems. Theoretically, M-ary digital modulation schemes using OFDM can accomplish a band width efficiency, defined as bit rate per unit bandwidth, of log2M bits/sHz (M is the modulation order).

As shown in Fig. 1 in the transmitter section, a convolutional encoder first encodes the binary input data. Coded bits are sent to interleaving and then the binary values are represented on quadrature amplitude modulation (QAM) values. To be able to adjust the signal in the receiver for a possible phase drift, pilot carriers can be inserted. In the serial to parallel block, the serial QAM input symbol-stream is transformed into a parallel stream with width equal to the number of sub-carriers. These parallel symbols are modulated onto the sub carriers by applying the inverse fast fourier transform. In order to get an output spectrum with a relative low out-of-band radiation, the size of the IFFT can be chosen larger than the amount of sub carriers that's actually spent to transmit the data. Following the IFFT block, the parallel output is converted back again to serial and guard interval, cyclic prefix of the time domain samples, is appended to eradicate ISI. IEEE 802.16+ grants the insertion of guard time intervals of several lengths such as 0.25, 0.125, 0.0625 and 0.03125 are lent to the WiMAX symbol earlier it is transmitted. The guard interval is more than the maximum delay time and then the inserted guard interval signal is D/A converted and passed through frequency selective fading channels. In the receivers, the guard interval is removed and the opposite processing is carried out to transmitter like time samples are converted by the FFT into complex symbols. The complex symbol is demodulated adaptively using adaptive modulation level information. Demodulated symbols are block de-interleaved. These bits are forwarded to Viterbi decoder. Decoded bits are going to be assigned to a specific user and then extracted utilizing the required bit rate information of the user.

## III. ADAPTIVE MODULATIONS AND CODING

The function of AMC is based on SDR-CR combination. The receiver evaluate received packets (i.e. SNR or BER) to estimate the Channel Quality Indictor (CQI) module, then feedback the transmitter to reconfigure itself for the next packet send. Once the receiver has estimated the channel SNR, converted it into BER information for each mode candidate, and, based on a target BER, selected the mode that yields the largest throughput while remaining within the BER target bounds, it has to feed back the selected mode to the transmitter in order that the adaptation can be performed. However, the challenge associated with adaptive modulation and coding is that the mobile channel is time varying, and thus, the feedback of the channel information becomes a limiting factor. Therefore, the assumption of a slowly-varying as well as a reliable feedback channel is necessary in order to achieve an accurate performance of the AMC scheme. In this way, no delay or transmission error can occur in the feedback channel so that no discrepancy between the predicted and the actual SNR of the next frame appears. Moreover, the receiver must also be informed of which demodulator and decoding parameters to employ for the next received packet. In this selection of modulation and coding rate schemes, SNR thresholds are defined from individual performance of every scheme in the channel maintaining target BER of 0.01 or 0.001. The AMC performance depends upon the accurate channel estimation at the receiver and the authentic feedback path between the receiver and the transmitter on that the receiver accounts channel state information (CSI). To ensure that for AMC scheme to have a good performance, the delay between the standard channel estimation and the specific transmission with regards to the morel Doppler frequency of the channel ought to be as little as possible. Also, the transmitter needs to alert the receiver which modulation and coding rate scheme will be used during the transmission. Otherwise, that will lead wrong demodulation and decoding of receiving packets which will compromise the performance.

## IV. SIMULATION RESULTS

In this paper, the OFDM parameters are centered on the WiMAX environment as shown in Table I. Specifically the attention is going to be mainly focused on BER performance of adaptive modulation schemes with Target-BER of 0.01 and 0.001. In order to select particular MCS at transmitter channel state information is given by the LSE and MMSE channel estimators. Fig. 2 shows the magnitude and the frequency response of QPSK modulation scheme with FFT size 1024 for WiMAX. BER vs. SNR values have been compared in the Tables II, III for BPSK, QPSK, 16QAM and 64QAM modulation schemes for different FFT sizes i.e. 256, 1024 and 2048. LSE and MMSE channel estimators response to the specific channel response indicates in Figs. 3-5.

In the beginning, an OFDM transmitter is integrated in establishing a physical layer of WiMAX is established using Matlab and AWGN channel is modeled to account for noise in the channel. Then channel estimation is performed by transmitting pilot subcarriers in receiver and correspondingly OFDM receiver is created. Fig. 6 shows the individual BER vs. SNR characteristics of different modulation schemes to be utilized in WiMAX without channel coding. QPSK has better BER performance than 64QAM. As shown in Fig. 6, BER value is increased with modulation order. Different MCS schemes i.e. 1/2 QPSK, 3/4 QPSK, 1/2 16-QAM, 3/4 16-QAM, 1/2 64-QAM and 3/4 64-QAM are used in transmitting and error rate is computed on bit by bit basis for every single iteration and average BER is calculated. Channel coding is inserted in wireless communication system to improve overall error rate performance as shown in Fig. 7. 3/4 64QAM depicted poor BER performance than remaining modulation schemes. Code rate along with modulation scheme effects BER performance of the physical layer system. Fig. 8 shows the throughput characteristics of different modulation schemes (QPSK, 16QAM, 64QAM) with code rate 1/2 and 3/4 in the AWGN channel evaluated by plotting the throughput Vs SNR characteristics. From Figs. 7 & 8, it can be concluded that 1/2 QPSK has better performance of BER but lesser throughput or spectral efficiency than other modulation and coding rate. Hence, we concluded that lower modulation & coding schemes are preferable for better BER performance and higher modulations & coding rates are more preferable to get higher throughput.

TABLE I
PARAMETER DEFINITION FOR MOBILE-WIMAX STANDARD

| Parameters | Values |
|---|---|
| Number of sub channels (N) | 1024 |
| Number of pilots (p=N/8) | 128 |
| Number of data subcarriers (N-P) | 896 |
| Guard interval length (GI=N/4) | 256 |
| Pilot position interval | 8 |
| Channel length | 16 |
| OFDM symbol time ($T_b$) | 91.4 µs |
| Guard time ($T_g$) | 11.4 µs |
| OFDM symbol duration (Ts= $T_b$+ $T_g$) | 1029 µs |
| Channel | AWGN, Rayleigh |
| Digital Modulations | BPSK, QPSK, 8PSK, 16QAM, 64QAM and 256QAM |

TABLE II
BER VS. SNR FOR LSE CHANNEL ESTIMATOR

| SNR db | BPSK FFT=256 | BPSK 1024 | BPSK 2048 | QPSK 256 | QPSK 1024 | QPSK 2048 |
|---|---|---|---|---|---|---|
| 0 | 0.5213 | 0.5000 | 0.4063 | 0.5000 | 0.4297 | 0.4609 |
| 5 | 0.5156 | 0.4375 | 0.4063 | 0.5781 | 0.4688 | 0.4219 |
| 10 | 0.4063 | 0.4531 | 0.4688 | 0.3984 | 0.5234 | 0.5000 |
| 15 | 0.4688 | 0.4228 | 0.3750 | 0.3828 | 0.4688 | 0.4219 |
| 20 | 0.4844 | 0.5156 | 0.4531 | 0.4844 | 0.4531 | 0.4766 |
| 25 | 0.5938 | 0.5781 | 0.5000 | 0.4844 | 0.4922 | 0.4922 |
| 30 | 0.4531 | 0.5000 | 0.3750 | 0.4844 | 0.4766 | 0.4804 |

TABLE III
BER VS. SNR FOR LSE CHANNEL ESTIMATOR

| SNR db | 16QAM FFT=256 | 16QAM 1024 | 64QAM 256 | 64QAM 1024 | 64QAM 2048 |
|---|---|---|---|---|---|
| 0 | 0.5313 | 0.5430 | 0.4922 | 0.5156 | 0.4922 |
| 5 | 0.4883 | 0.4766 | 0.4818 | 0.5026 | 0.4695 |
| 10 | 0.4805 | 0.5156 | 0.4974 | 0.4657 | 0.4922 |
| 15 | 0.4492 | 0.4453 | 0.4714 | 0.4635 | 0.4714 |
| 20 | 0.5078 | 0.4961 | 0.4844 | 0.5078 | 0.5651 |
| 25 | 0.5273 | 0.5391 | 0.5339 | 0.4896 | 0.4948 |
| 30 | 0.4648 | 0.4648 | 0.4896 | 0.5078 | 0.4661 |

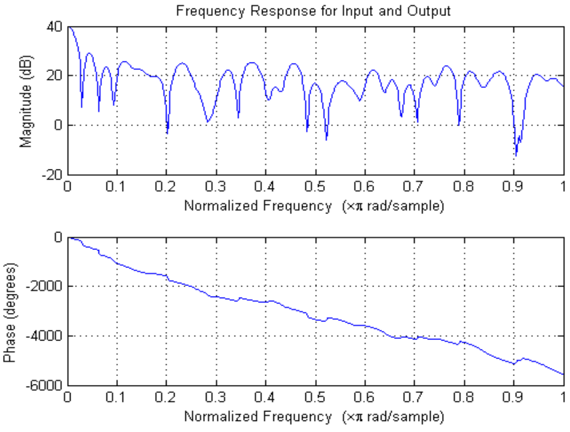

Fig. 2 Magnitude and Phase response for LSE channel estimator with FFT size 1024

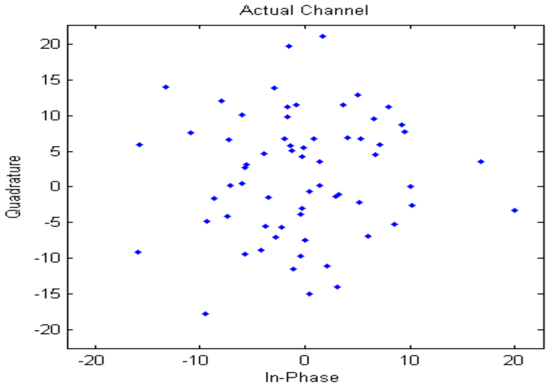

Fig. 3 Actual channel response

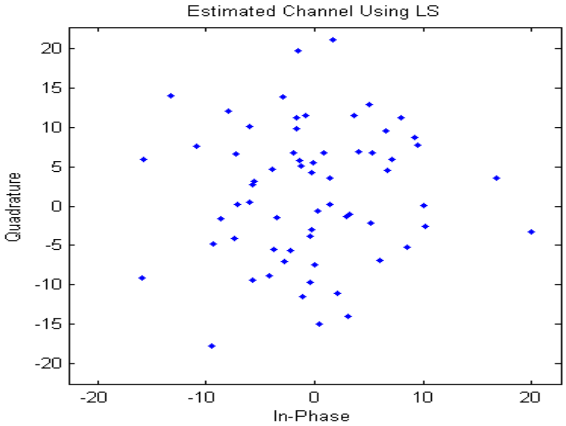

Fig. 4 Channel response by LSE channel estimator

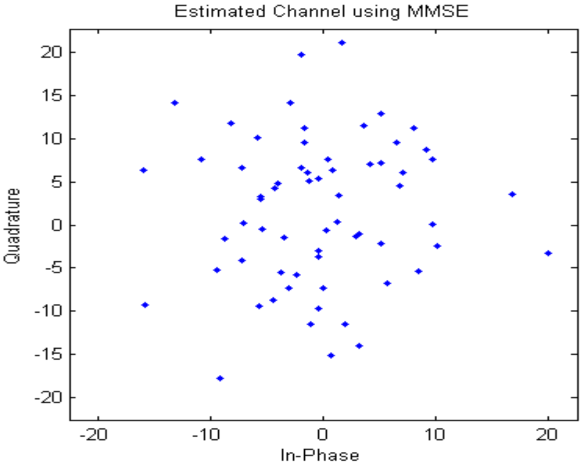

Fig. 5 Channel response by MMSE channel estimator

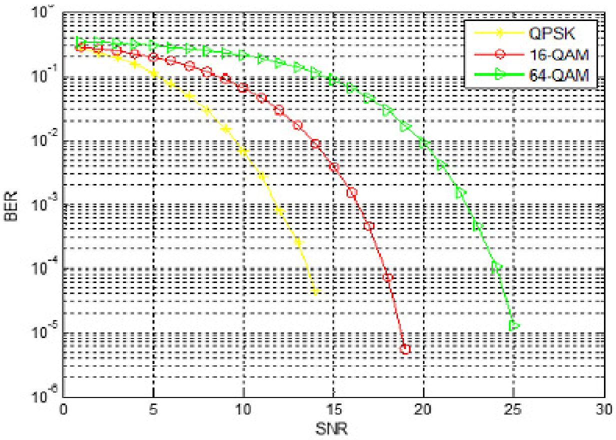

Fig. 6 BER performance without channel coding

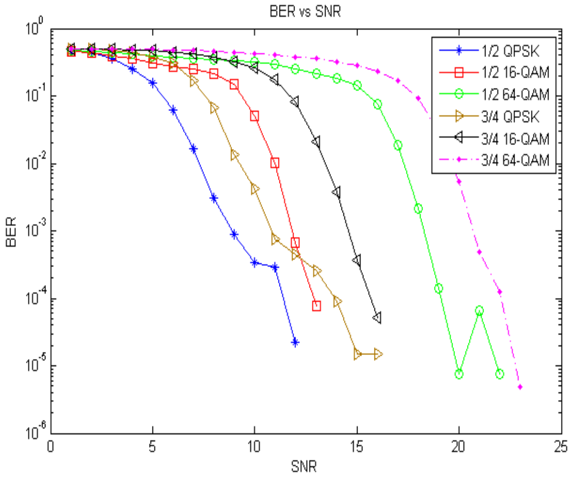

Fig. 7 BER performance of AMC system with convolutional channel coding

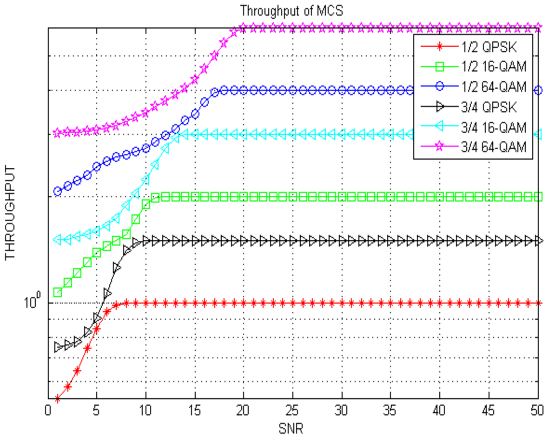

Fig. 8 Throughput performance of different MCS schemes

The Target BER technique employed for AMC scheme is performed keeping in mind the error rate under a target limit say 0.01 or 0.001, maintaining a fixed level quality level of service with regards to error probability. Table IV shows the SNR threshold to alter different modulation and coding rate based on SNR for target BER of 0.01. The Target BER technique operation is that the system keeps dealing with the lowest modulation and coding scheme, namely QPSK modulation with coding rate 1/2, until the signal-to-noise ratio allows to respect the error rate constraint, then the system switches on higher modulation transmission schemes to yield a much better spectral efficiency while maintaining our desired BER target. If input data streams are transmitted using 64 QAM with a coding rate of 3/4, the throughput is going to be maximized but there will be lower BER performance. So by compromising slightly the throughput performance, the modulation and coding rate schemes are changed to keep the error rate below our desired BER level. Fig. 9 compares the throughput performance for Target BER 0.01 and 0.001. High throughput curve exhibits high BER value which is a trade-off.

TABLE IV
SWITCHING THRESHOLDS FOR AMC SYSTEM

| MCS schemes | SNR thresholds (dB) Target-BER=0.01 | SNR thresholds (dB) Target-BER=0.001 |
|---|---|---|
| 1/2 QPSK | < 8 | < 10 |
| 3/4 QPSK | 8 - 10 | 10 - 11 |
| 1/2 QAM16 | 10 - 12 | 11 - 13 |
| 3/4 QAM16 | 12 - 16 | 13 - 18 |
| 1/2 QAM64 | 16 - 18 | 18 - 20 |
| 3/4 QAM64 | > 18 | > 20 |

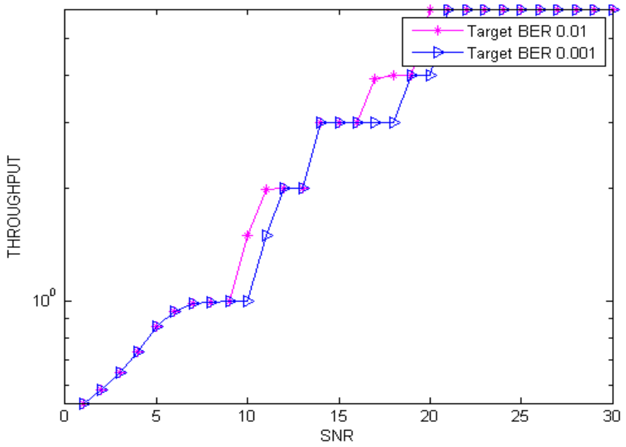

Fig. 9 Throughput comparison of Target-BER 0.001 and 0.01

Fig. 10 shows the plot drawn between Spectral efficiency Vs. CINR with fixed code rate of 1/2. The spectral efficiency achieved with AM (adaptive modulation), BPSK, QPSK and 16-QAM are 3, 0.5, 1 and 2 (in bps/Hz) (noted from Fig. 10).

Fig. 11 shows the plot drawn between Spectral efficiency Vs. CINR with fixed code rate of 5/6. The spectral efficiency achieved with AM, BPSK, QPSK and 16-QAM are 5, 1, 1.5, 3.5 and 5 (in bps/Hz) (noted from Fig. 11). From these results, authors concluded that AM provides better spectral efficiency than any other FM (fixed modulation) schemes for all CINR values. Higher modulation scheme (64QAM) gives high spectral efficiency as much as AM. Furthermore, higher code rate (5/6) have better spectral efficiency than lower code rate (1/2). From Figs. 7-11, it can be concluded that higher code rates have high spectral efficiency, higher throughput but poor BER performance.

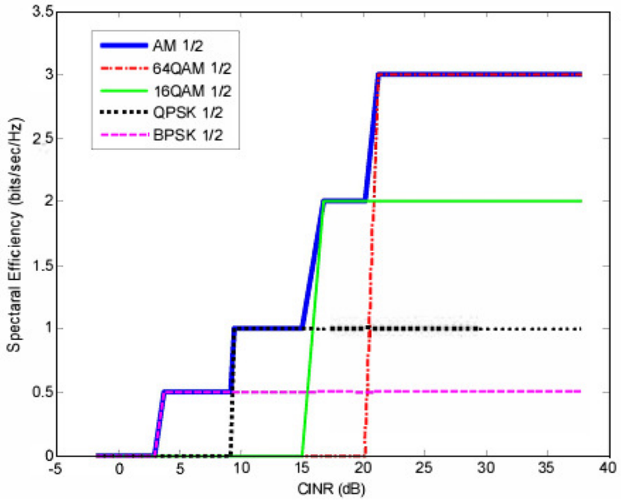

Fig. 10 Spectral efficiency vs CINR with fixed code rate of 1/2

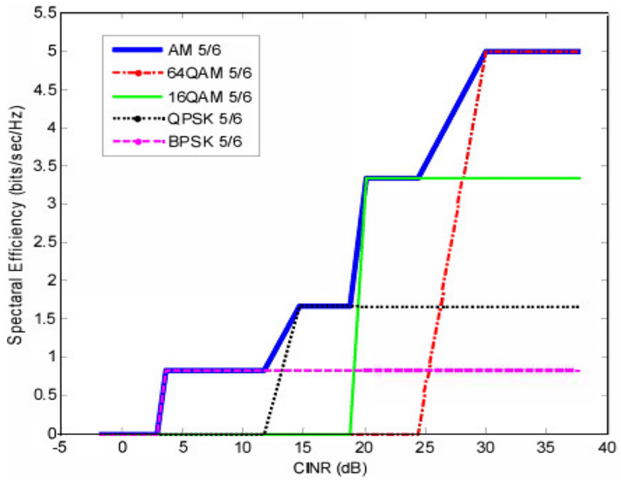

Fig. 11 Spectral efficiency vs CINR with fixed code rate of 5/6

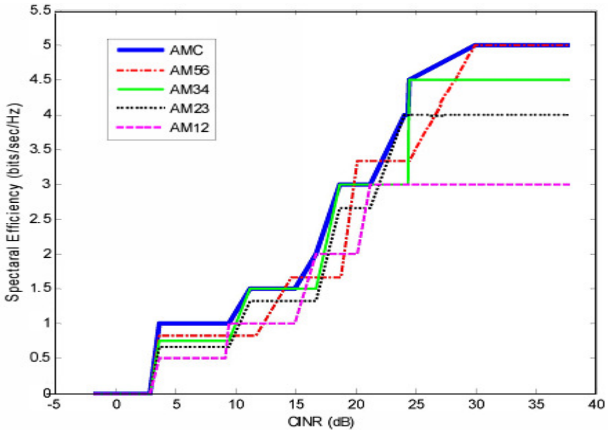

Fig. 12 Spectral efficiency of AMC and AM with CINR

So this trade-off has to be satisfied while choosing a particular modulation and coding systems. AMC (combining

AM and AC) provides higher spectral efficiency than AM and FM schemes as presented in Fig. 12. However, the maximum spectral efficiency that is yielded by using AMC or AM with fixed code rate 1/2 or AM with fixed code rate 5/6 is 5 bps/Hz. However, AMC provides higher throughput performance than AM or FM for all modulation schemes as shown in Fig. 12.

Fig. 13 shows the BER performance Rician fading channels [10] for 16QAM modulation scheme with 1024 IFFT/FFT size. It can be concluded that, with-out channel estimation the BER has constant performance for all modulation schemes in both the channels.

So, without channel estimation, the selection of the proper modulation scheme is difficult based on channel conditions. As modulation size increases, the BER value also increases at a given SNR value, which is a tradeoff. The BER value decreases as SNR increases, but increasing SNR is a tradeoff in low power systems.

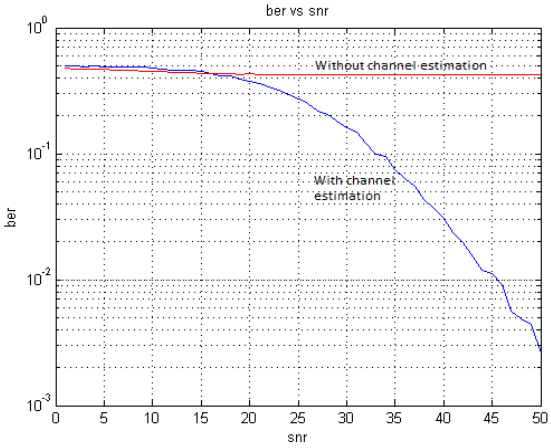

Fig. 13 Rician fading channel performance for 16QAM modulation scheme

Fig. 14 presents a scatter plot that shows the signal before and after equalization, as well as the signal constellation for QPSK modulation. The equalized symbols are clustered more concisely around the points of the received signal constellation. The clustering of the symbols will be changed according to the equalizer's algorithm used.

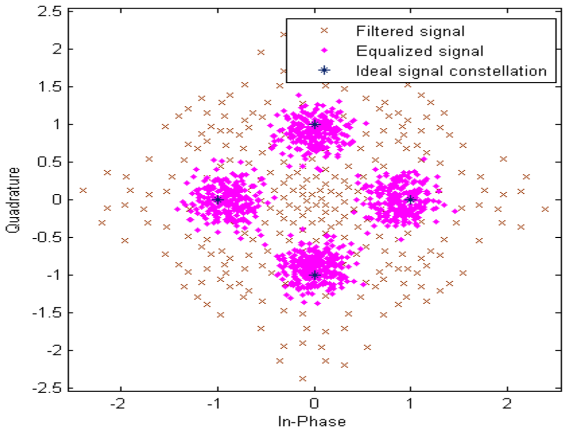

Fig. 14 Received signal constellation with equalizer

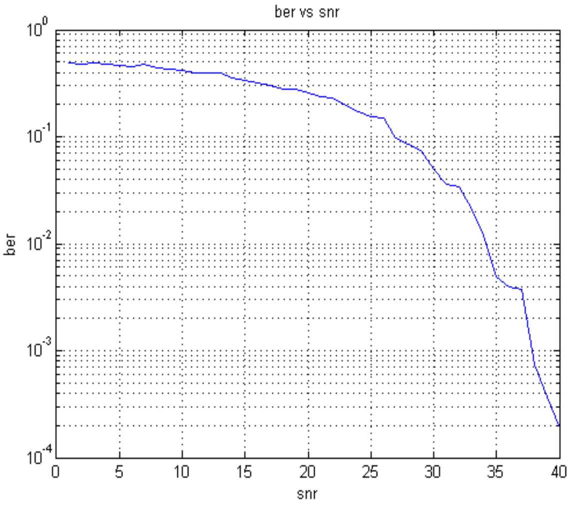

Fig. 15 BER performance of LMMSE channel estimator over AWGN channel

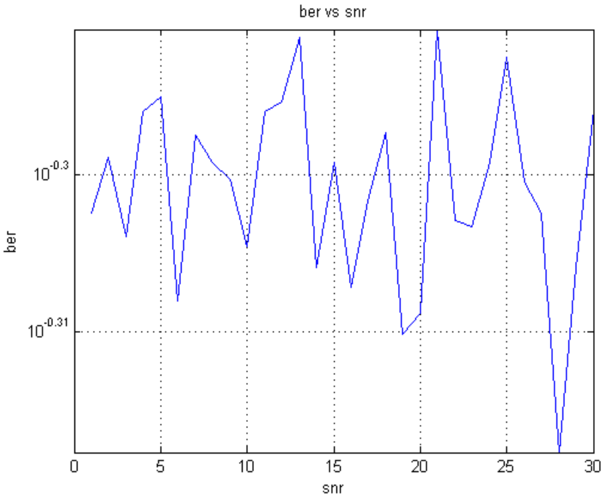

Fig. 16 BER performance of LMMSE channel estimator over Rayleigh fade channel

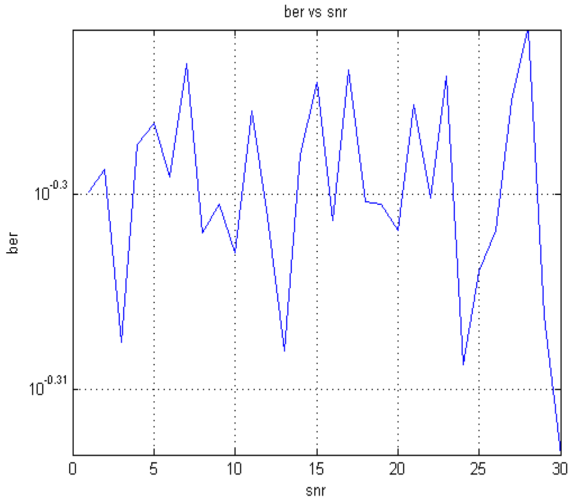

Fig. 17 BER performance of LMMSE channel estimator over Rician fade channel

BER values for Rayleigh and Rician fading channels with different modulation schemes (BPSK, QPSK, 16QAM, 64QAM and 256QAM) over LSE channel estimator are arranged in Table V. As modulation size increments, the BER value likewise increases at a given SNR value, which is a trade-off. BER value is diminished with SNR increment but increasing SNR is a trade-off in low power systems.BER execution is analyzed by varying channel model for LMMSE estimator are noted in Table VI by utilizing plots demonstrated within Figs. 15-17. BER is low for AWGN channel compared with Rayleigh and Rician fade channels. The BER is reduced gradually for AWGN and varies arbitrarily for remaining channels. Henceforth, modulation and coding rates are changed adaptively for AWGN as indicated in Fig. 7. BER execution for AWGN, Rayleigh and Rician channels are demonstrated in Figs. 18 and 19 under Target BER 0:01 and relating values are noted in Table VII. It could be concluded that BER performance is good (BER is low) for AWGN channel compared to consider remaining multipath fading channels.

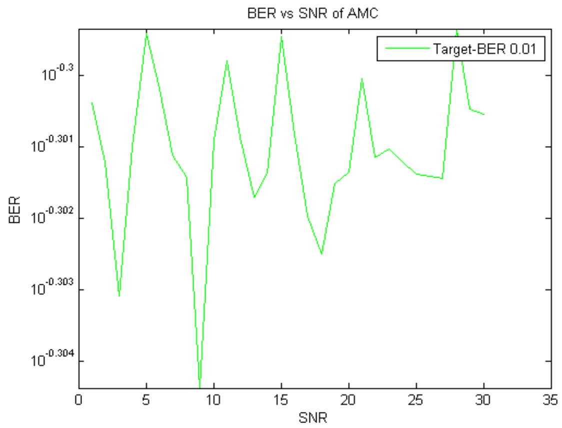

Fig. 18 BER performance of AMC system under Target-BER 0.01 over Rayleigh channel

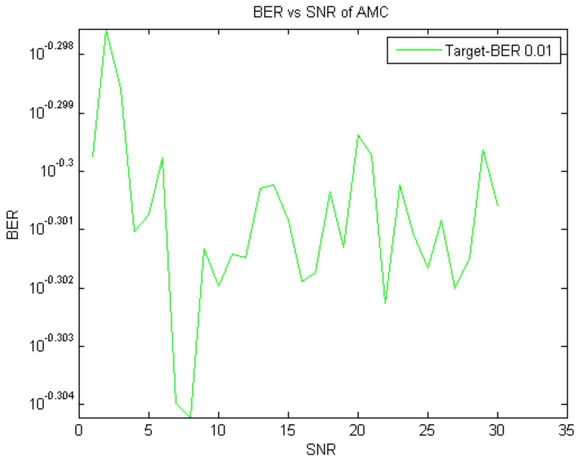

Fig. 19 BER performance of AMC system under Target-BER 0.01 over Rician channel

TABLE V
BER VS SNR PERFORMANCE FOR CHANNELS OVER LSE CHANNEL ESTIMATOR

| **Modulation scheme** | **Rayleigh SNR=30dB** | **Rayleigh 45dB** | **Rician 30dB** | **Rician 45dB** |
|---|---|---|---|---|
| BPSK | 0.0316 | 0.0010 | 0.0630 | 0.01 |
| QPSK | 0.0501 | 0.0015 | 0.0794 | 0.00154 |
| 16QAM | 0.10115 | 0.00316 | 0.11748 | 0.01047 |
| 64QAM | 0.10471 | 0.01584 | 0.13182 | 0.02691 |
| 256QAM | 0.15848 | 0.06309 | 0.16595 | 0.1 |

TABLE VI
BER VS SNR PERFORMANCE FOR CHANNELS OVER LMMSE CHANNEL ESTIMATOR

| **Channel** | **BER at SNR= 5 dB** | **BER 10 dB** | **BER 15 dB** | **BER 20 dB** | **BER 25 dB** | **BER 30 dB** |
|---|---|---|---|---|---|---|
| AWGN | 0.316 | 0.251 | 0.199 | 0.158 | 0.125 | 0.039 |
| Rayleigh | 0.506 | 0.497 | 0.501 | 0.490 | 0.510 | 0.504 |
| Rician | 0.505 | 0.496 | 0.506 | 0.500 | 0.495 | 0.484 |

TABLE VII
BER VS SNR PERFORMANCE FOR CHANNELS OVER LMMSE CHANNEL ESTIMATOR UNDER TARGET BER=0.01

| **Channel** | **BER at SNR= 20 dB** | **Maximum BER** | **Minimum BER** |
|---|---|---|---|
| AWGN | 0.003 | 0.316 | 0.00003 |
| Rayleigh | 0.499 | 0.506 | 0.496 |
| Rician | 0.501 | 0.504 | 0.496 |

## V. CONCLUSIONS

This paper evaluated the WiMAX PHY performance in terms of BER, throughput, SNR, CINR and spectral efficiency with adaptive modulation techniques. We investigated the impact of employing the link adaptation techniques on the spectral efficiency of the mobile WiMAX networks. Evaluation results showed that employing link adaptation techniques significantly improves the performance of mobile WiMAX. It was found that AM improves the system performance in terms of the average spectral efficiency compared with any FM schemes everywhere in the cell. Furthermore, AMC, that is a combination of adaptive modulation and adaptive coding, significantly improved the system performance better than the improvement that was obtained with AM alone. The results concluded that higher modulation schemes give higher data rate, but gives higher BER value. Lower modulation schemes give a better BER performance, but poor throughput performance. So, care has to be taken while selecting a particular modulation technique by keeping all these tradeoffs in mind.

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