On BER Performance Enhancement of WiMAX PHY layer with STBC Encoding for Fixed and Mobile Users

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***Abstract*— In this paper the performance of PHY layer of WiMAX is investigated and implemented with Space Time Block Coding (Alamouti scheme, STBC) and Forward Error Correction (FEC) for both Fixed and Mobile User environments. The results show that by implementation of STBC scheme in WiMAX PHY results in low BER, thus a WiMAX network with improved BER performance is developed from the investigations.**

***Index Terms*— WiMAX; IEEE 802.16; PHY layer; QoS; STBC scheme.**

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) is global broadband wireless system based on IEEE 802.16 standard intended for wireless "metropolitan area networks" for providing high quality broadband services to fixed, portable and mobile users. WiMAX combines high data rate services with wide area coverage (in frequency range of 10 – 66 GHz (Line of sight) and 2 -11 GHz (Non Line of Sight)) and large user densities with a variety of Quality of Service (QoS) requirements. The WiMAX standard defines the air interface for the IEEE 802.16d-2004 [1] specification for stationary transmission, and 802.16e specification for both stationary and mobile deployments [2]. One of the innovative adaption in WiMAX PHY layer is the use of OFDM (Orthogonal Frequency Division Multiplexing) and Orthogonal Frequency Division Multiple Access (OFDMA) [3] for fixed (256- point FFT) and mobile communications (128 bits to 2,048 point FFT) intended for higher data rate transmissions with reduced Inter Symbol Interference (ISI) in non-line-of-sight or multipath environments. Scalable OFDMA (SOFDMA) had also been introduced in IEEE 802.16e to support scalable channel bandwidths from 1.5 to 20 MHz with guaranteed bandwidth of up to 15 Mbps. The power and spectral efficiency become necessary as the demand for high data rate applications increase. One of the solution for reducing the power requirement, increased reliability, link capacity and spectral efficiency is the application of multiple/input multiple output (MIMO) techniques. The combination of OFDM/OFDMA and MIMO adds to the multiplexing gain, the broadband performance, frequency reuse and SNR improvement through mitigation of multipath effects [4-5].

This paper deals with the modelling and analysis of PHY layer in a WiMAX based network using Space Time Block coding (STBC) which is introduced for improvement in QoS performance of the network. The paper is organized as follows: a brief description of IEEE 802.16 PHY is provided in Sections 2. Section 3 describes the STBC diversity. Section 4 describes the equivalent system and network model developed for analysis in MATLAB™. Explanation of the results obtained via simulation is done in Section 5, and finally the work is concluded in Section 6.

II. IEEE 802.16 PHYSICAL LAYER

The IEEE 802.16 standard [7-8] supports multiple physical specifications which make the standard adaptable to different frequency ranges and enables the system designers to tailor their system according to the requirements. The PHY specifies some mandatory features to be implemented with the system including some optional features to provide a reliable end-to-end link. Table 1 summarizes various OFDM parameters used in WiMAX.

Table 1: OFDM PARAMETERS USED IN WIMAX

Parameter	Fixed WiMAX (OFDM PHY)	Mobile WiMAX Scalable OFDMA-PHY			
FFT Size	256	128	512	1024	2048
Number of used subcarriers	192	72	360	720	1440
Cyclic Prefix	1/32, 1/16, 1/8, 1/4				
Channel bandwidth (MHz)	3.5	1.25	5	10	20

The PHY layer of 802.16 standard provides various QoS mechanisms with features including Frequency Division Duplex (FDD) and Time Division Duplex (TDD) to provide bandwidth allocation flexibility, OFDM/OFDMA to provide greater spectral efficiency, Adaptive PHY profile: to provide ability to switch the Radio Link Control (RLC) to a more robust and efficient PHY technology (burst profile including the UL (Uplink) or DL (Down Link), Modulation type, FEC, preamble length, guard time), depending on channel conditions, Hybrid Automatic Repeat Request (HARQ): to ensure a more reliable transmission of data. The combination of these QoS mechanisms in PHY layer helps to reduce latency, jitter, packet loss, interference and increase the capacity (throughput) of the system to achieve the desired goals of QoS. Further, when implemented with different architectures [8] and mobility protocols [19] a high

degree of QoS based interworking system with other service technologies (i.e. UMTS- WiMAX, WiMAX-WLAN) can also be achieved.

III. IEEE 802.16 D/E DIVERSITY

One of the important WiMAX PHY layer mechanisms is diversity which provides multiple received signals with different fading patterns and significantly reduces the probability that all the received signals are in a fade at the same time and thus improves the average error rate of the system. The three main forms of diversity used are: Time Diversity, Frequency Diversity and Spatial Diversity [14-15]. Time Diversity is achieved by repeatedly transmitting the same signal in different time slots, where the separation between the successive time slots equals or exceeds the coherence time of the channel. The WiMAX system takes advantage of time diversity by incorporating FEC in physical layer. Frequency diversity is achieved by OFDM by providing simultaneous modulation signals with error control coding across a large bandwidth, so that if a particular frequency undergoes a fade, the composite signal is demodulated [14] i.e. multicarrier modulation. Spatial diversity can be created without using the additional bandwidth that time and frequency diversity both require [12-13]. In addition to providing spatial diversity, antenna arrays can also be used to focus energy (beam forming) or create multiple parallel channels for carrying unique data streams (spatial multiplexing). When multiple antennas are used at both the transmitter and the receiver, these three approaches are often collectively referred to as multiple/input multiple output (MIMO) communication. MIMO systems have the ability to exploit NLOS channels of mobile WiMAX, and hence increase spectral efficiency as compared to Single-Input Single- Output (SISO) system. MIMO advantages include diversity gains, multiplexing gains, interference suppression and array gains. Mobile WiMAX supports a full range of smart antenna technologies, including Space Time Block Codes (STBC), Spatial Multiplexing (SM), and beam forming and is intended to increase the SNR, data rate and spectral efficiency.

The array gain and probability of error rate of a $N_t \times N_r$ diversity system is given by:

$$\gamma_D = \frac{N|h|^2}{\sigma^2} \quad (1)$$

$$P_b \approx C_m \gamma^N \quad (2)$$

Where γ_D is SNR of the diversity system, N is the diversity order given by: $N = N_t \times N_r$; P_b is the bir error probability; C_m is the constant which depends on the modulation type and γ is the received SNR.

A significant improvement in array gain and reduction in the error rate is indicated by (1) and (2) in comparison to system with no diversity.

The most commonly used diversity technique is STBC which sends the data stream through different antennas encoded in blocks which are distributed among spaced antennas and across time for N_t transmit and N_r receive antennas. A simpler 2 x 1 or 2 x 2 Alamouti STBC [15] scheme is used to provide both time diversity and space diversity. The Alamouti STBC provides full diversity with little or no rate penalty and uses the maximum likelihood decoding at the receiver. Space-Time coded orthogonal frequency division is multiplexing technique [15] which combines OFDM with Alamouti STBC, figure 1.

C_1 and C_2 are two different sets of symbols, each containing a number of symbols equal to the number of used carriers transmitted, from two antennas in the first time slot and $-C_2^*, C_1^*$ in the second time slot. At a given symbol period, the OFDM blocks transmitted from the first antenna and second antenna are:

$$C_1 = c_1[1].c_1[2]...c_1[K] \quad (3)$$

$$C_2 = c_2[1].c_2[2]..c_2[K] \quad (4)$$

where $c_i[p]$ is the symbol from the *i* th OFDM block transmitted on the *p* th carrier and *K* is the number of carriers. During the next symbol period, the block $-c_2^*$ is transmitted from the first antenna and the block c_1^* is transmitted from the second antenna.

The receive antenna obtains the signals r_1, r_2 over the two consecutive time slots for codeword given by:

$$\begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ -h_2^* & h_1^* \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (5)$$

where h_1 and $h_2$are the path gains from the two transmit antennas and the noise samples n_1 , n_2 are independent samples of a zero-mean complex Gaussian random variable with noise energy N_0 per complex dimension. The soft estimates for transmitted signals $c_1[k]$ and $c_2[k]$ at the *j*th receive antenna can then be calculated from [19].

$$\begin{bmatrix} c_1^{\sim j}[k] \\ c_2^{\sim j}[k] \end{bmatrix} = \begin{bmatrix} |H_{1j}[k^2]| + |H_{2j}[k^2]| & 0 \\ 0 & |H_{1j}[k^2]| + |H_{2j}[k^2]| \end{bmatrix} \times \begin{bmatrix} c_1[k] \\ c_2[k] \end{bmatrix} + \begin{bmatrix} n_{1j}[k] \\ n_{2j}[k] \end{bmatrix} \quad (6)$$

Where $H_{ij}[k]$ denotes the normalized channel frequency response for the *k*th tone, corresponding to the channel between the *i*th transmit antenna and the *j*th receive antenna. In order to anlayze the performance, PHY layer model for WiMax Network is developed usinf STBC encodr and Decoder from the standard documents with Matlab R2007a and is briefly described below.

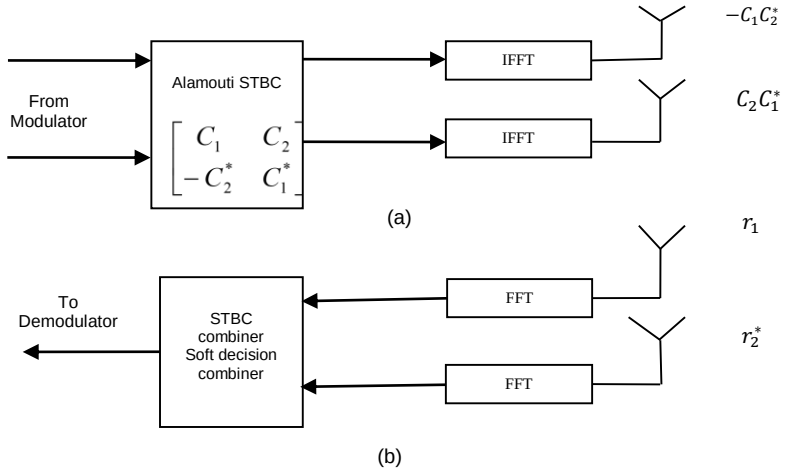

Figure 1. Space-frequency coded OFDM system: (a) Transmitter (Encoder) (b) Receiver (Decoder)

IV. STBC ENCODED WIMAX PHY LAYER MODEL

Space-time block codes form an optional feature in WiMAX PHY that can be implemented in the downlink to provide increased diversity [8-18] and coding gain. Therefore in this paper the basic PHY layer model is investigate developed and analyzed by implementing STBC encoding to realise first order IEEE 802.16 d/e diversity. The PHY layer model is developed including Forward Error Correction (FEC) and interleaving. FEC is done in two phases through the outer Reed Solomon (RS) and inner Convolutional Code (CC). The complementary operations are applied in reverse order at channel decoding in the receiver end, figure2.

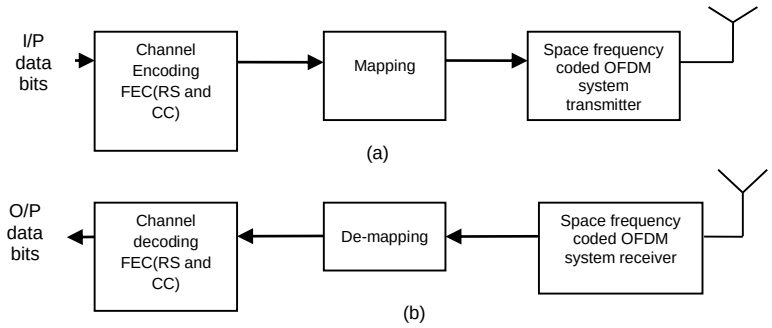

Figure 2. PHY layer model (a) Transmitter (b) Receiver

The Alamouti 2x1 Encoder is applied to the system is in accordance with the figure 1 and eqns. (3), (4), (5 and 6 with j =1). The wireless channels modeled are ITU- A vehicular and ITU – B pedestrian models to incorporate different terrain scenarios and mobility types with path loss (including shadowing) multipath delay spreads, fading characteristics, Doppler spread, co channel and adjacent channel interference

V. RESULTS AND PERFORMANCE ANALYSIS

The reliability of physical-layer is measured in terms of average bit error rate. The BER curves are obtained for the WiMax PHY layer implemented in the system for OFDM-STBC technique and varying parameters (FEC and channel conditions) to characterize its performance. Figure 3 shows that the introduction of FEC in the PHY layer improves the performance at low SNR in fading environments encountered by a mobile user.

Simulations were further carried out to analyze the performance of a STBC encoder for different modulation systems. Figure 4 compares the BER performance of STBC encoder (2x1 and 2x2) with SISO (1x1) system in Rayleigh channel for BPSK ½ and QPSK ½ modulation schemes. The results show that a high relative gain is obtained from the STBC encoder. At the BER of 10^{-3} a gain of 8 dB for 2x1 STBC encoder and 16 dB for 2x2 STBC encoder from BPSK ½ SISO system is observed while for QPSK ½ a gain of 10 dB for 2x1 encoder and 18 dB for 2x2 encoder is obtained, a better gain performance for higher modulation scheme i.e. QPSK ½ is observed. Thus, the relative gain shows that there is improvement in performance of the system (both QPSK ½ and BPSK ½) in multipath environment with STBC encoder, thus making it an ideal candidate to combat fading in wireless channels.

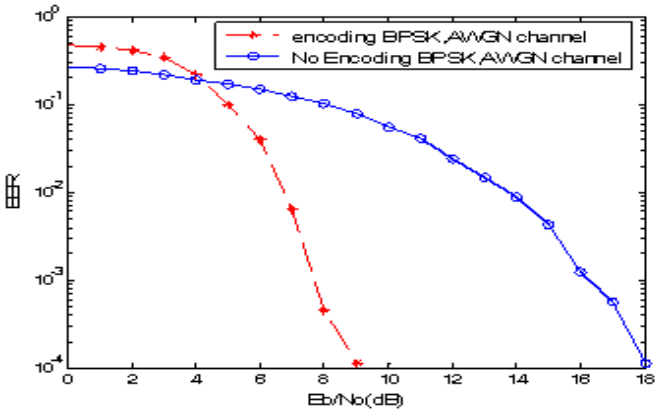

Figure 3. Performance of system with BPSK1/2 system for FEC and No FEC (mobile user)

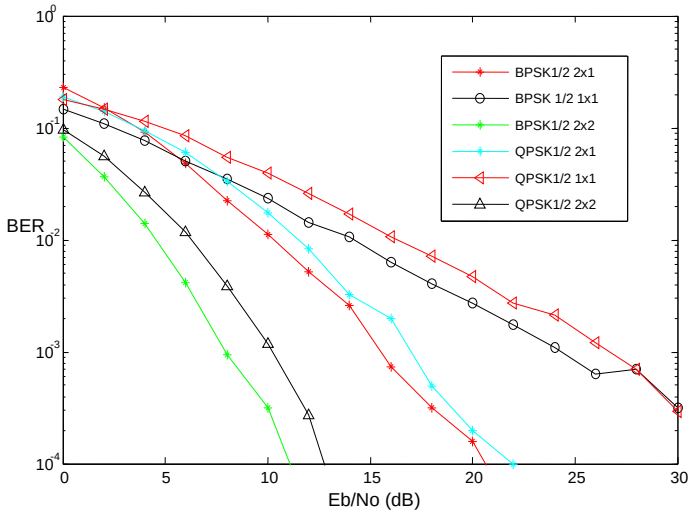

Figure4. Performance of STBC encoder for a BPSK ½ and QPSK ½ system in Rayleigh faded channel.

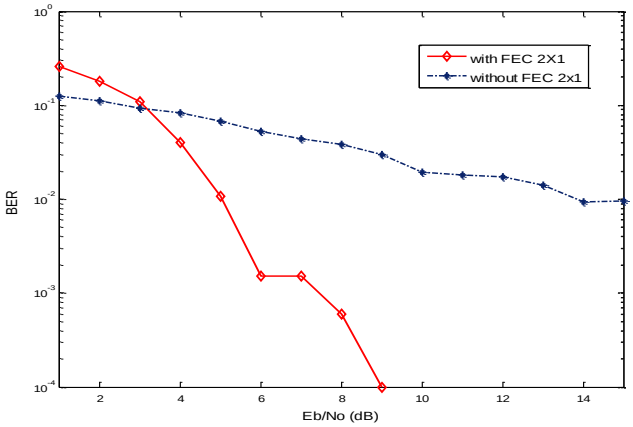

Figure 5. STBC 2x1 with FEC encoded BPSK ½ system.

A combination of FEC and STBC is then implemented in a BPSK ½ system and improvement in performance by a factor of 9 dB is observed, figure 6. It was inferred that FEC improves the performance of STBC encoder. With the results obtained above the WiMAX PHY is then analyzed for Space- Frequency Coded OFDM system (OFDM with 2x1) with FEC. The results obtained in figure 5 reveal that the Space- Frequency Coded OFDM system in the WiMAX PHY efficiently exploits the time diversity (FEC), spatial diversity (STBC) and frequency diversity (OFDM) offered to a mobile user (3 km/h) in the fading channel (ITU channel vehicular A) by offering a lower BER performance.

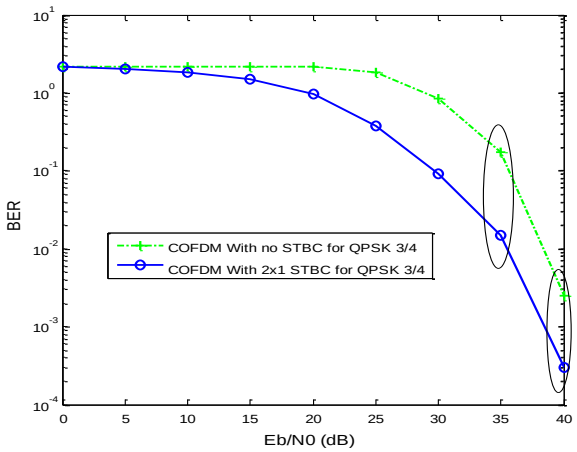

Figure 5. STBC 2x1 in QPSK ¾ based system (PHY layer): for mobile user

VI. Conclusion

A comprehensive evaluation of performance of IEEE 802.16d/e based PHY layer is done by implementing its various key aspects and with STBC and FEC. The results obtained show that STBC enhance the performance of the PHY layer of the WiMAX network for both fixed and mobile environments. Lower BER obtained indicates that the performance of PHY layer is increased with STBC which can hence significantly improve the QoS of WiMAX based networks [19].

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