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On Performance Enhancements of WiMax PHY Layer with Turbo Coding for Mobile Environments

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Abstract

IEEE 802.16d/e PHY layer adapted by WiMax forum includes multiple specifications, which make the standard flexible and adaptable to different frequency ranges. The PHY layer specifies some mandatory features and some optional features to be implemented to provide a reliable end-to-end link. The primary issue in implementation of PHY layer is robust performance in multipath fading environments. In this paper, the performance of WiMax PHY layer with turbo coding mechanisms is investigated and compared with the existing mechanisms. The results obtained show that turbo coding offers lower BER and enhance the performance of the PHY layer in mobile (multipath) environments.

Keywords: *WiMax; IEEE 802.16 PHY layer, Turbo coder*

1. Introduction

Worldwide Interoperability for Microwave Access (WiMAX) is an emerging global broadband wireless system based on IEEE 802.16 standard. WiMAX is a new OFDM based technology and promises to combine 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 [1, 2]. WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed station and 3 to 10 miles (5-15 km) for mobile stations with theoretical data rates between 1.5 and 75 Mbps per channel. The 802.16e standard is an amendment to 802.16d standard and adds new major specifications enabling full mobility at vehicular speed with increased QoS to it (below 6 GHz NLOS operation). The WiMAX standard air interface includes the definition of both the medium access control (MAC) and the physical (PHY) layers for the subscriber station and base station while the access network operability is defined by the WiMAX Forum, an organization consisting of operators and component and equipment manufacturers [3].

The IEEE 802.16 standard supports multiple physical specifications which increase the flexibility of PHY layer and enables the system designers to tailor their system according to their 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. WiMax PHY layer uses OFDM (Orthogonal Frequency Division Multiplexing) and Orthogonal Frequency Division Multiple Access (OFDMA) [4] for fixed (256- point FFT) and mobile communications (128 bits to 2,048 point FFT). This adaptation provides higher data rate transmissions with reduced Intersymbol 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.

In order to meet the requirements of increased spectral efficiency and higher data rate applications in both fixed and mobile environments, the IEEE 802.16 standard provides powerful tools known as mechanisms at PHY layer level to support flexibility and efficiency over a range of different applications and environments with higher QoS [5]. One of the important mechanisms is combination of modulation schemes with forward error correcting codes (FEC). Wherein, a high transmission speed is provided by a high order modulation scheme but it makes more susceptibility to interference. FEC builds redundancy into the transmission by repeating some of the information bits, so bits that are missing or in error can be corrected at the receiving end and helps to reduce latency by cutting down the retransmissions. Without FEC error correction would require whole frames to be retransmitted, resulting in latency and lower QoS. There are three basic types of forward error correction codes: block codes (Reed Solomon codes), convolutional codes and turbo codes. The Reed-Solomon Convolutional Code (RS-CC) are the mandatory schemes in IEEE 802.16 PHY layer standard, while Convolutional Turbo Code (CTC) and Block Turbo Code (BTC) are both optional and basically intended for mobile environments [6].

In this paper the behavior of IEEE 802.16 standard based PHY layer for WiMax system is analyzed with and without Turbo codes for mobile environments.

Following this introduction a brief description of PHY model and turbo coding used in the analysis is given in Sections II and III. Explanation of the results obtained via simulation is done in Section III. Finally the work is concluded in Section IV.

2. Physical (PHY) Layer Model Description

The primary function of WiMAX PHY is the actual physical transport of data. To achieve maximum performance for high data rate transmission (both in fixed and mobile environments) and high spectral efficiency with diverse QoS requirements it supports variety of PHY mechanisms with features including:

2.1 Frequency Division Duplex (FDD) and Time Division Duplex (TDD): Provides bandwidth allocation flexibility.

2.2. OFDM/OFDMA: OFDM technique is a bandwidth efficient multicarrier technique, which splits the system bandwidth into orthogonal sub channels, each of which occupies only a narrow bandwidth and a separate sub carrier is assigned to each. By means of guard interval and cyclic prefix, an OFDM system also achieves good resistance against multipath fading.

2.3. Adaptive PHY profile: Provides 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) [13], Modulation type, Forward Error Correction (FEC, preamble length, guard time), adaptive antenna systems and advance OFDM systems. depending on channel conditions.

2.3.1. Adaptive Modulation and coding: WiMax supports link adaptation techniques known as adaptive modulation and coding in which the modulation scheme changes depending on channel conditions. Using adaptive modulation scheme, WiMax system can switch to the highest order modulation depending on the channel conditions. AMC technique helps to reduce the time selective fading, increase the range that a higher modulation scheme can be used over [5].

2.3.2. Forward Error Correction (FEC): It is achieved using convolutional codes (correct independent bit errors) and Reed Solomon codes (correct burst errors at byte level) to provide the additional coding gain which measures the amount of additional SNR that would be required to provide the same BER performance for an uncoded message signal in the same channel conditions. The RS coder is particularly useful for OFDM links in the presence of multipath propagation while the puncturing functionality in CC made the concatenated codes rate compatible as per specification. Table 2 summarizes several combinations of modulation and coding rates, which can be allocated selectively to each subscriber (both UL and DL), specified by the PHY layer [5].

2.3.3. Optional Supports: Apart from the mandatory schemes mentioned above several optional supports have also been included in the PHY layer standard. These include: channel coding schemes such as block turbo codes, convolutional turbo codes, and low density parity check (LDPC) codes to increase the coverage and/or capacity [6]; both transmit and receive diversity to enhance performance in fading environments through spatial diversity for increasing the capacity of the system; hybrid-ARQ which is an effective hybrid between FEC and ARQ for enhanced reliability; a signaling structure that enables the use of adaptive antenna system (AAS) to enable the transmission of DL and UL burst using directed beams, each intended for the BS [6]; advanced OFDM systems (MC –CDMA) to support multi-user diversity.

Table 2. Different Modulation And Coding Rates

Modulation	RS Code	CC code	Coding rate
QPSK	(32,24,4)	2/3	1/2
QPSK	(40,36,2)	5/6	3/4
16-QAM	(64,48,8)	2/3	1/2
16-QAM	(80,72,4)	5/6	3/4
64-QAM	(108,96,6)	3/4	2/3
64-QAM	(120,108,6)	5/6	3/4

3. Turbo Coding in IEEE 802.16 Standard

Turbo codes are provided as an optional channel coding scheme in IEEE 802.16 standard. Turbo codes are basically convolutional codes concatenated in series or in parallel and are generally known as convolutional turbo codes (CTC). The IEEE 802.16 uses duo binary turbo codes in which a pair of bits is used for encoding in both the regular and interleaved coding iterations with a constituent recursive encoder of constraint length 4, figure 1.

In duo binary turbo codes two consecutive bits from the uncoded bit sequence are sent to the encoder simultaneously with two generating polynomials, $1+D2+D3$ and $1+D3$ for two parity bits. Since two consecutive bits are used as simultaneous inputs, this encoder has four possible state transitions compared to two possible state transitions for a binary turbo encoder. Duo binary turbo codes are have better convergence; larger minimum distances and less sensitivity to puncturing patterns [7]. The output of the native 1/3 coding rate encoder is first separated in six different blocks(A,B, Y1, Y2, W1 and W2) where A and B contain the system bits, Y1 and W1 contain the parity bits of the encoded sequence in natural order, and Y2 and W2 contain the parity bits of the interleaved sequence. Each of the blocks is independently interleaved and the sub blocks that contain the parity bits are punctured (remove some of the parity bits after encoding) to achieve the target code rate. The sub block interleaver is composed of two stages: (1) The first stage of the interleaver flips bits contained in the alternating symbol.2 (2) The second stage of the sub block interleaver permutates the positions of the symbols.

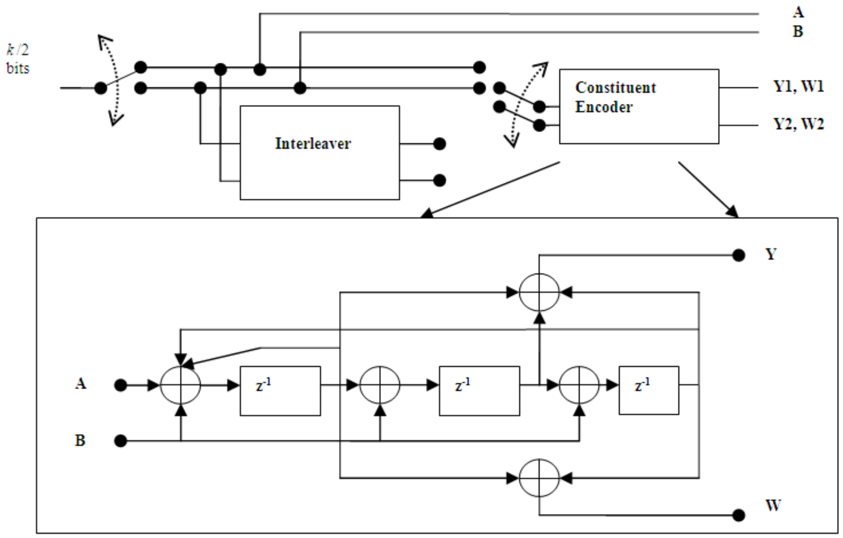

Figure1. Conventional Turbo Encoder in IEEE 802.16e-2005 Standard [5].

Table 3. Look Up Table for CRSC Coder

N_{mod}	Circulation state (S_{N-1})							
	0	1	2	3	4	5	6	7
1	0	6	4	2	7	1	3	5
2	0	3	7	4	5	6	2	1
3	0	5	3	6	2	7	1	4
4	0	4	1	5	6	2	7	3
5	0	2	5	7	1	3	4	6
6	0	7	6	1	3	4	5	2

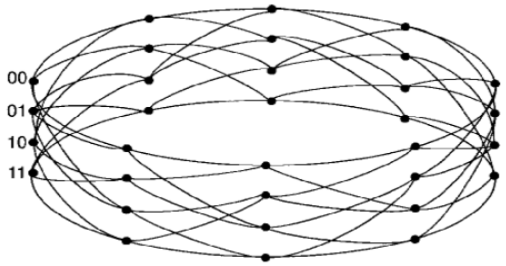

Figure 2. 4-State Trellis Code Structure

In order to achieve the target code rate, the interleaved sub blocks Y1, Y2, W1, and W2 are punctured using a specific puncturing pattern This CTC encoder fed by blocks of *k* bits or *N* pairs ($k = 2 * N$ bits), *k* is a multiple of 8 and *N* is a multiple of 4 and $8 \leq N / 4 \leq 1024$. the In order to overcome the decoding loses additional “dummy” tail bits at the end of the information sequence are inserted and the encoder is initialized in the memory so that the final state of the encoder register becomes equal to the initial state and the resulting code trellis has a circular representation and are known as circular non-recursive convolutional codes (CRSC) codes [8]. According to the encoder structure given in figure 1, a 4 state trellis diagram and a look up table is obtained, figure 2 and table 3. The decoder is similar to that of classical Turbo code with CRSC as the sub code.

4. Modeling and Simulation

The PHY layer model is developed from the standard documents with MATLAB™ R2007a. The basic system model developed and analyzed in [10] is investigated further with introduction of Turbo Coder, figure 3.

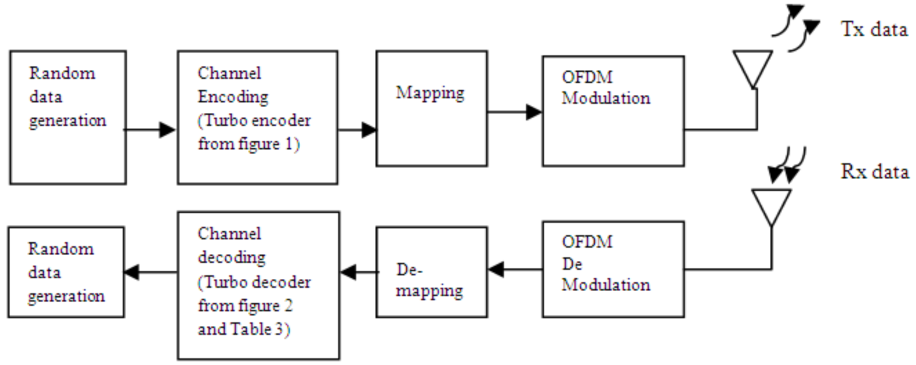

Figure3. Schematic Turbo Encoded WiMax PHY Layer Model Developed in Matlab 2007a

The randomly generated data is turbo encoded (replaced for FEC), mapped and then OFDM modulated in transmitter. The reverse of operations is carried out in receiver. The wireless channels modeled are in accordance with ITU- A vehicular 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 for mobile environments [9]

The CTC encoding is performed using 5 functions including initial state of encoder (pre coding), state transition matrix, CTC encoding, sub block interleaving, puncturing (symbol selection). The CTC encoding and decoding process implemented is described next:

1. Look up table: This table is determined for state-transition-matrix as per table 3.
2. Pre coding: Determining the initial circular state of register, namely pre-coding with state transform formula:

$$(i + 1) = A * S(i) + B * U(i) \quad \ldots (1)$$

   To obtain: [A, B, Y1, Y2, W1, W2] state of the encoder
3. CTC encoding : It is performed by

$$S(i) = A * S(i - 1) + B * U(i) \quad \ldots (2)$$

$$Y(i) = C * S(i) + D * U(i) \quad \ldots (3)$$

4. Sub block interleaving: After encoding the symbols are interleaved and are read out in a permuted order with the ith symbol read from an address, [8].
5. Symbol Grouping: The interleaved A & B sub block sequence is followed by a symbol-by-symbol multiplexed sequence of interleaved Y1& Y2, W1 & W2 sub block sequences. Here each sub block sequence consists of 1st bit from first sub block (e.g. Y1), and 1st output bit from second sub block (e.g. Y2).
6. Puncture (symbol selection): This involves the symbol selection technique to be followed depending on the number of bits in the encoder packet before encoding, number of subchannel allocated for sub packet and modulation order.

The CTC decoder is then implemented as reverse of encoding process as : restoring sequence from sub block interleaving, symbol grouping and selection by arrange the demodulated sequence into [A, B, Y1, Y2]; padding punctured bit with 0; then separating Y1 & Y2 into different column followed by sub block de-interleaving and then CTC decoding block by block.

The various parameters that are used for schematic evaluation are summarized in Table 4.

Table 4. Parameters for Simulation

Parameter	Value
Modulation scheme	QPSK ½, QPSK ¾
Channel model	AWGN channel, ITU vehicular A for mobile user.
CP length	1/16
Channel Bandwidth	5 MHz
No. of users and speed of user	1; 100 km/h (for mobile)

5. Results and Analysis

The performance of Turbo coded PHY layer of WiMax system for different modulation techniques with varying channel conditions is measured in Bit Error Rate (BER) curves. A comparative performance analysis with FEC encoder based WiMax PHY layer has also been carried out.

Figure 4 compares the performance of turbo coded WiMax PHY layer in AWGN channel for QPSK ½ and QPSK ¾ system. The result obtained is in accordance with [10] that higher modulation scheme offer better performance at high values of SNRs while lower order schemes perform better for lower SNRs.

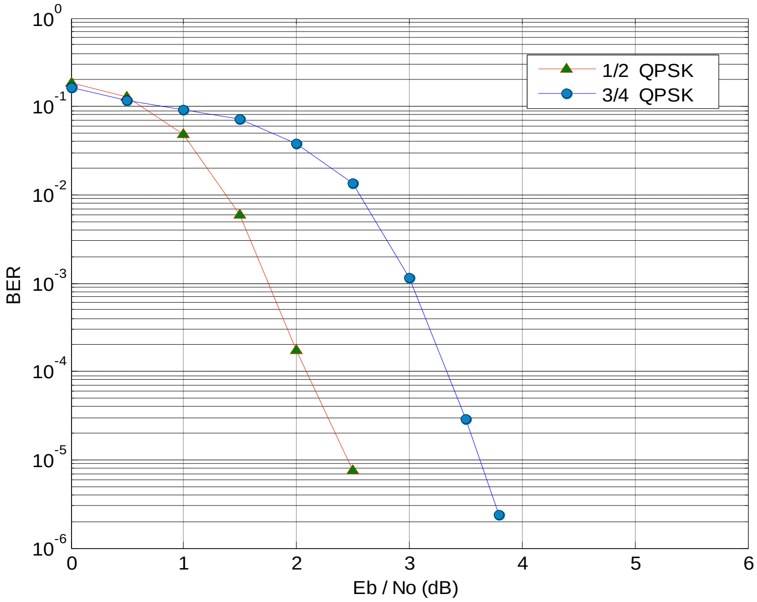

Figure 4. BER Performance of Turbo Coded WiMax System in AWGN Channel for QPSK ¾ and QPSK ½ System.

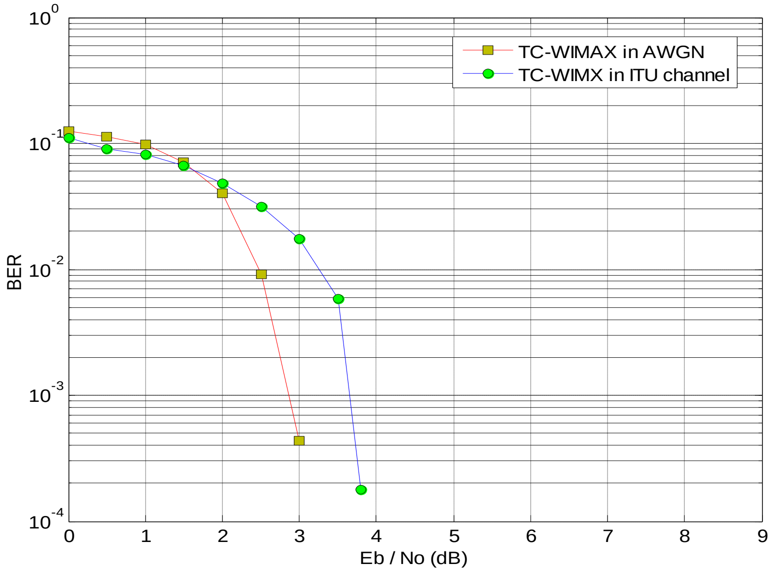

Figure 5. BER performance of Turbo Coded WiMax system in AWGN Channel and ITU Vehicular Channel for Mobile user for QPSK ¾ System

Figure 5 shows the performance of turbo coded system for a mobile user in a QPSK ¾ system. It is observed that mobile user have higher BER than fixed one performance this is on the account of the multipath fading environment encountered by a mobile user. Figure 6 compares the performance of Turbo coded WiMax system and FEC coded WiMax system for a mobile user. An improvement of ~5 dB is observed with the introduction of Turbo coding in the PHY layer of the WiMax system. Thus it is inferred that introduction of turbo encoding in the WiMax PHY layer reduces the BER and hence improves the performance in multipath fading environments.

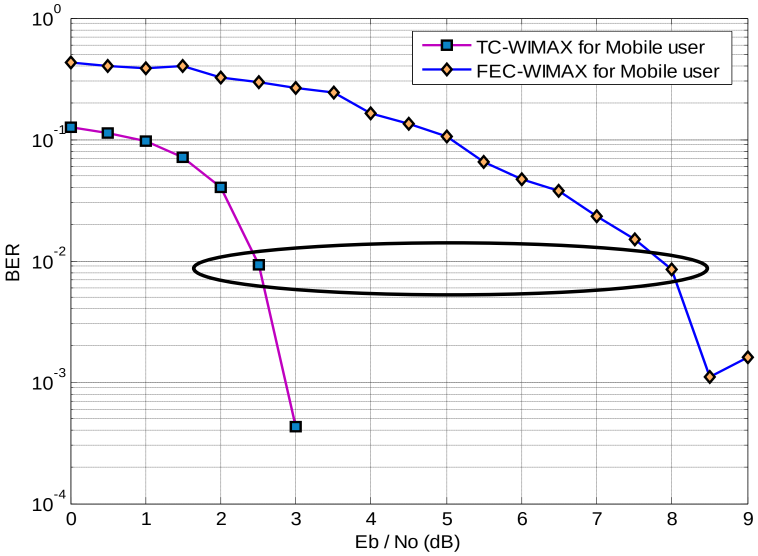

Figure 6. BER Performance of Turbo Coded WiMax System and FEC Coded WiMax System in ITU-A Vehicular Channel for QPSK ¾ System.

Table 5. Performance Improvement by Turbo Encoder for WiMax QPSK ¾ System

WiMax PHY layer profile Eb/No (dB)	FEC encoded	Turbo encoded
Eb/No(dB) at BER of 10^{-2}	**8**	**2.5**
Eb/No(dB) at BER of 10^{-3}	**8.5**	**3**

However, the gain is observed at the expense of longer delays in processing of the signals which results from the increased complexity of the system and can be overcome with improved turbo encoder designs.

6. Conclusions

The performance of IEEE 802.16d/e based PHY layer is investigated by implementing its various key aspects in mobile environments. The investigations are carried further with the implementation of the optional feature of turbo coding in the PHY layer of the WiMax system. The results obtained show that performance of WiMax system can be optimized to a lower BER of 10^{-2} at 3dB SNR with the introduction of turbo coding in multipath fading environments.

Our paper focuses basically on improvement of WiMAX PHY layer performance for a single mobile user with the introduction of turbo coder in the PHY layer of the system. The OFDM-turbo coded PHY layer has been found to outperform the OFDM-FEC based PHY layer with the only constraint of increased delay owing to increased memory states and complexity of the system the decoder. The improved interleaver design and memory efficient decoding algorithms can further be implied to overcome these delays.

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