The WiMAX 802.16e Physical Layer Model

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Abstract

The emergence of WiMAX has attracted significant interests from all the fields of wireless communications including students, researchers, systems engineers and operators. WiMAX has been tipped to bring a revolution in the way we use broadband services today. The WiMAX can also be considered to be the main technology in the implementation of other networks like wireless sensor networks. Developing an understanding of the WiMAX system can be best achieved by looking at a model of the WiMAX system. This paper discusses the model building of the WiMAX Physical layer using Simulink in Matlab. This model is a useful tool for performance evaluation of the WiMAX under different data rates, coding schemes and channel conditions besides serving as a helpful resource for the students and the researchers who want to base their studies and research on the fields related to the WiMAX. Standards from IEEE and ETSI have been used to develop this model. The model presented in this paper built with generic MAC PDU processed by the Physical Layer using Convolutional Encoding Rate of 5/6 with QPSK modulation and transmitted with 256 carrier OFDM symbols.

1 Introduction

WiMAX is an IEEE 802.16 standard based technology responsible for bringing the Broadband Wireless Access (BWA) to the world as an alternative to wired broadband. The WiMAX standard 802.16e provides fixed, nomadic, portable and mobile wireless broadband connectivity without the need for direct line-of-sight with the base station. It is different from the previous versions of the standard in the sense that 802.16e adds the feature of mobility to the wireless broadband standard.

The model implemented in this paper is based on the WiMAX which has the following characteristics [5].

Standard:	IEEE 802.16e
Carrier Frequency:	Below 11GHz
Frequency Bands:	2.5GHz, 3.5GHz, 5.7GHz
Bandwidth:	1.5MHz to 20MHz
Radio Technology:	OFDM and OFDMA
Data Rate:	70 Mbps
Distance:	10 km

The significance of building a model for this standard can be established by considering the effect that a model can bring on the overall project development lifecycle. If a model for a system is developed after the design phase and tested correctly then early detection of a problem with the design is possible. This will reduce the time and cost to change the design at the later stages of the development.

Once a model is built, tested and verified against a set criterion then using tools like Simulink and Matlab could be helpful in generating the code and exporting the model in suitable formats for implementation in hardware processors.

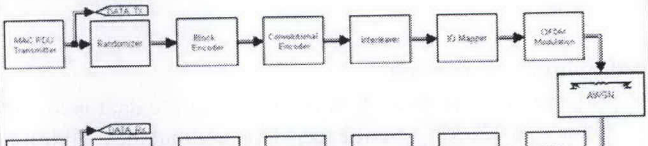
Models for other IEEE standards such as Bluetooth and Wireless LAN have been developed in the past using Matlab. There was a need to build a model for the WiMAX on similar lines to fill the gap. Mathworks, the vendors for the Matlab software have put together a White Paper [6] on this topic of creating an executable specification in Simulink for WiMAX and that paper is a useful resource to follow and build a model from scratch.

2 The WiMAX Model

The Model for the WiMAX is built from the standard documents [1,2]. The model presented in this paper is built on the following parameters:

Scenario:	16-Channel Full Bandwidth
Modulation:	QPSK (QPSK is same as 4-QAM)
RS Code Rate:	3/4
CC Code Rate:	5/6

The modelling setup includes Matlab R2007a, Simulink7 and Communications Blockset 3 running on Windows XP SP2. Matlab Simulink includes all the mandatory function blocks as specified by the standard documents. The Model itself consists of three main components namely transmitter, receiver and channel. Transmitter and receiver components consist of channel coding and modulation sub-components whereas channel is modelled as AWGN.



The WiMAX Model in Matlab Simulink

2.1 Channel Coding

Channel coding can be described as the transforming of signals to improve communications performance by increasing the robustness against channel impairments such as noise, interference and fading.

The coding is carried out on the data sequences by altering the characteristics of the sequences. The converted sequences then have structured redundancy which enables decision process, by a transmitter or a receiver, less subject to errors.

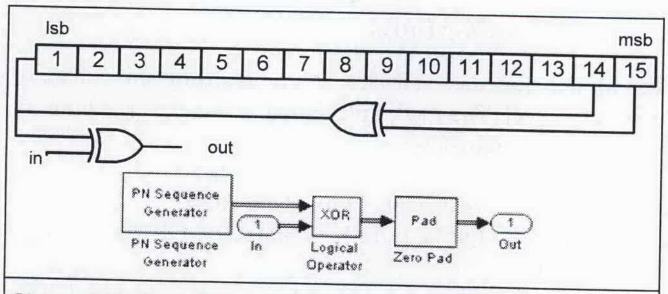
Channel Coding can be described as a three phase process including Randomization, Forward Error Correction and Interleaving.

2.1.1 Randomization

Randomization is the first process carried out in the physical layer after the data packet is received from the higher layers. Each burst in Downlink and Uplink is randomized.

Randomizer operates on a bit by bit basis. The purpose of the scrambled data is to convert long sequences of 0's or 1's in a random sequence to improve the coding performance.

The main component of the data randomization is a Pseudo Random Binary Sequence generator which is implemented using Linear Feedback Shift Register.



Channel Coding - Data Randomizer

The generator defined for the randomizer is given by Equation (1)

$$1 + x^{14} + x^{15} \qquad (1)$$

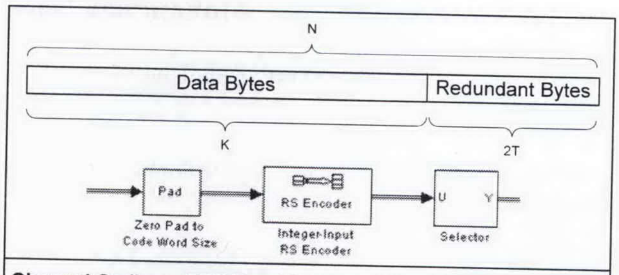
2.1.2 Forward Error Correction (FEC)

Forward Error Correction is done on both the Uplink and the Downlink bursts and consists of concatenation of Reed-Solomon Outer Code and a rate compatible Convolutional Inner Code.

Reed Solomon Encoding

The purpose of using Reed-Solomon code to the data is to add redundancy to the data sequence. This redundancy addition helps in correcting block errors that occur during transmission of the signal.

After randomizer data is passed onto the Reed Solomon Encoder. The encoding process for RS encoder is based on Galois Field Computations to do the calculations of the redundant bits. Galois Field is widely used to represent data in error control coding and is denoted by GF(2^m).



Channel Coding – FEC Reed Solomon Encoder

WiMAX uses a fixed RS Encoding technique based on GF(2^8) which is denoted as RS(N = 255, K = 239, T = 8)

Where:
N = Number of Bytes after encoding
K = Data Bytes before encoding
T = Number of bytes that can be corrected

Eight tail bits are added to the data just before it is presented to the Reed Solomon Encoder stage. This stage requires two polynomials for its operation called code generator polynomial g(x) and field generator polynomial p(x). The code generator polynomial is used for generating the Galois Field Array whereas the field generator polynomial is used to calculate the redundant information bits which are appended at the start of the output data.

These polynomials are defined by the standard [1] as below:

Code Generator Polynomial:

$$g(x) = (x + \lambda^0)(x + \lambda^1)(x + \lambda^2)(x + \lambda^3) .. (x + \lambda^{2T-1}) \qquad (2)$$

Field Generator Polynomial:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \qquad (3)$$

Convolutional Encoding

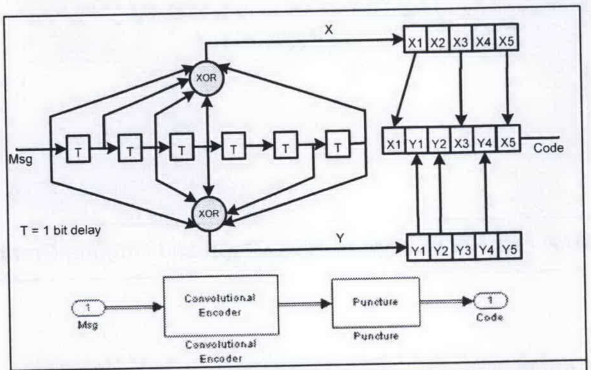
Convolutional codes are used to correct the random errors in the data transmission. A convolutional code is a type of FEC code that is specified by CC(m, n, k), in which each m-bit information symbol to be encoded is transformed into an n-bit symbol, where m/n is the code rate ($n \geq m$) and the transformation is a function of the last k information symbols, where k is the constraint length of the code [5].

To encode data, start with k memory registers, each holding 1 input bit. All memory registers start with a value of 0. The encoder has n modulo-2 adders, and n generator polynomials, one for each adder.

In WiMAX Physical Layer each RS block is encoded by the binary convolutional encoder, which has a code rate of ½ and a constraint length equal to 7. This encoder has two binary adders X and Y and uses two generator polynomials, A and B. These generator polynomial codes are:

$A = 171$ octal $= 1111001$ binary for X (4)
$B = 133$ octal $= 1011011$ binary for Y (5)

The output of the convolutional encoder is then punctured to remove the additional bits from the encoded stream. The number of bits removed is dependent on the code rate used.

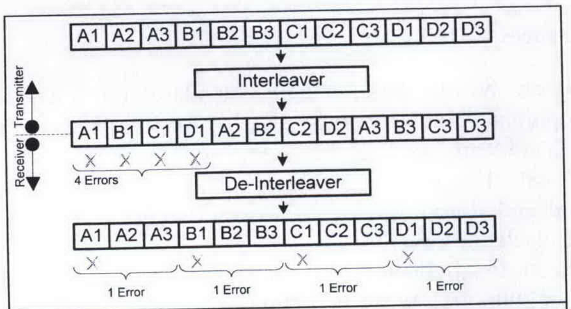


Channel Coding – FEC Convolution and Puncturing

2.1.3 Interleaving

Interleaver in its most basic form can be described as a randomizer but it is quite different from the randomizer in the sense that it does not change the state of the bits but it works on the position of bits.

Interleaving is done by spreading the coded symbols in time before transmission. The incoming data into the interleaver is randomized in two permutations. First permutation ensures that adjacent bits are mapped onto non-adjacent subcarriers. The second permutation maps the adjacent coded bits onto less or more significant bits of constellation thus avoiding long runs of less reliable bits.



Channel Coding - Interleaving and Deinterleaving

The block interleaver interleaves all encoded data bits with a block size corresponding to the number of coded bits per OFDM symbol. The number of coded bits depends on the modulation technique used in the Physical layer. WiMAX 802.16e supports 4 modulation techniques and is adaptive in the selection of a particular technique based on the channel conditions and data rate.

WiMAX 802.16e defines two permutations for the interleaver.

The first permutation is defined by the formula:
$mk = (Ncbps/12) * \mathrm{mod}(k,12) + \mathrm{floor}(k/12)$ (6)

The second permutation is defined by the formula:
$s = \mathrm{ceil}(Ncpc/2)$ (7)
$jk = s \times \mathrm{floor}(mk / s) +$
$(mk + Ncbps - \mathrm{floor}(12 \times mk / Ncbps))\mathrm{mod}(s)$ (8)

where:

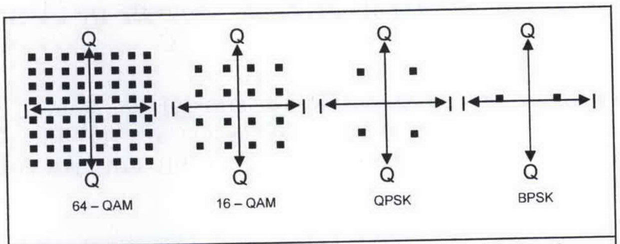
Ncpc	= Number of coded bits per carrier
Ncbps	= Number of coded bits per symbol
k	= Index of coded bits before first permutation
mk	= Index of coded bits after first permutation
jk	= Index of coded bits after second permutation

Same permutation is done on the receiver side to rearrange the data bits into the correct sequence. Index of bits represented by jk is used during the modulation process.

2.2 Modulation

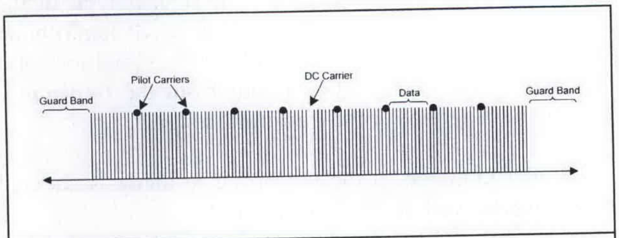
The interleaver reorders the data and sends the data frame to the IQ mapper. The function of the IQ mapper is to map the incoming bits of data from interleaver onto a constellation.

In the modulation phase the coded bits are mapped to the IQ constellation, starting with carrier number –100 on up to carrier number +100. To simplify transmitter and receiver designs, all symbols in the FCH and DL data bursts are transmitted with equal power by using a normalization factor.



IQ Mapper Operation in WiMAX 802.16e

The constellation-mapped data is subsequently modulated onto all allocated data carriers in order of increasing frequency offset index.



OFDM Transmission Structure

Guard band, pilot carriers and DC carrier are inserted in the structure before using the IFFT to convert the frequency domain signals into time domain. These time domain signals are then transmitted through the channel.

2.3 Implementation Considerations

While implementing the model it is assumed that the receiver and the transmitter are fully synchronised and there is no delay. Adaptive modulation is not implemented in the current model.

3 The WiMAX Model Test Results

The WiMAX standard document [2] provides several test cases and test vectors for each test case. Below are the test results for each component in hexadecimal format.

Data Payload from the MAC Layer (29 bytes frame)
45 29 C4 79 AD 0F 55 28 AD 87 B5 76 1A 9C 80 50 45 1B
9F D9 2A 88 95 EB AE B5 2E 03 4F 09 14 69 58 0A 5D

Data Frame after Randomization Stage (35 bytes frame)
D4 BA A1 12 F2 74 96 30 27 D4 88 9C 96 E3 A9 52 B3 15
AB FD 92 53 07 32 C0 62 48 F0 19 22 E0 91 62 1A C1

Data Frame after Reed-Solomon Encoding (40 bytes frame)
49 31 40 BF D4 BA A1 12 F2 74 96 30 27 D4 88 9C 96 E3
A9 52 B3 15 AB FD 92 53 07 32 C0 62 48 F0 19 22 E0 91 62
1A C1 00

Data Frame after Convolutional Encoding (48 bytes frame)
3A 5E E7 AE 49 9E 6F 1C 6F C1 28 BC BD AB 57 CD BC
CD E3 A7 92 CA 92 C2 4D BC 8D 78 32 FB BF DF 23 ED
8A 94 16 27 A5 65 CF 7D 16 7A 45 B8 09 CC

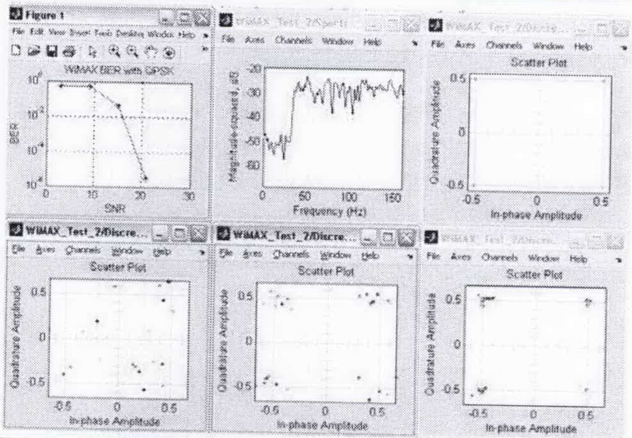
Data Frame after Interleaving (48 bytes frame)
77 FA 4F 17 4E 3E E6 70 E8 CD 3F 76 90 C4 2C DB F9 B7
FB 43 6C F1 9A BD ED 0A 1C D8 1B EC 9B 30 15 BA DA
31 F5 50 49 7D 56 ED B4 88 CC 72 FC 5C

3.1 Performance Evaluation

Based on the model presented in this paper, and tests carried out, the performance was established based on 10 million symbols in each case. The performance is displayed in the following figure in terms of the BER versus SNR logarithmic plot, time-scatter plots for 10, 20 and 30dB Signal-to-Noise Ratios, time-scatter plot for the output from the transmitter and FFT scope diagram for the transmitted signal.

The BER plot obtained in the performance analysis showed that model works well on SNR above 20dB.

The time-scatter plots demonstrate the scattering of the transmitted and received signals at different values of the Signal-to-Noise Ratios. It also shows that at very low SNR the symbols are very difficult to recognise.



WiMAX Test Result: Inputs, BER Graph and Outputs Graphs

3.2 Conclusions

The model built in this paper demonstrates the importance of modelling a system to understand its functionality. Tests can be carried out on the model to calculate the performance indicators. Components of the system can be tested against a defined standard, IEEE 802.16e in this case, to prove the complete working of the component itself and the system as a whole. The same model can be used to implement coding and modulations schemes. The results of the simulation from the models will enable the researchers to choose the best option for their requirements. In future this model can be expanded to include the components of the MAC layer and a complete end to end WiMAX system could be built based on this model.

References

[1] IEEE 802.16-2006: "IEEE Standard for Local and Metropolitan Area Networks - Part 16: Air Interface for Fixed Broadband Wireless Access Systems"

[2] ETSI TS 102 177 Version 1.3.1, February 2006, "Broadband Radio Access Networks (BRAN); HiperMAN; Physical (PHY) Layer"

[3] Practical Applications for Wireless Networks, Paris, 10 October 2006, IET Workshop 2006

[4] WiMAX and Mesh Networks, London, 14-15 June 2005, IEE Seminar 2005

[5] Nuaymi Loutfi, 2007, WiMAX Technology for Broadband Wireless Access, Wiley, London

[6] Mathworks Whitepaper, 2006, "Creating an Executable Specification for WiMAX Standard"