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The WiMAX Physical layer modeling for image processing application

[1]Kaushal P. Makhecha , [2]Sandip J. Dawda, [3]Anil C. Suthar

[1]P.G.Student, E. C. Dept, C. U. Shah College of Engg.& Tech., Surendranagar
[2]Lecturer, E. C. Dept, C. U. Shah College of Engg.& Tech., Surendranagar
[3]Asst. Prof. ,E. C. Dept, C. U. Shah College of Engg and Tech., Surendranagar
[1]kaushalmakhecha@ieee.org , [2] sandipdawda@yahoo.co.in ,[3]acsuthar@ieee.org

***Abstract* — Now age is of accessing image and video accessing with the higher speed and mobility. So one must require wireless broadband networks with higher data rates. WiMAX will give the solution of higher data rate and 8 to 10 Km mobility. Developing an understanding of the WiMAX system can be best achieved by looking at a model of the WiMAX system. In this paper, we deal with the physical layer of WiMAX system for image processing. This model is very useful to analyse the WiMAX system. We use OFDM and OFDMA for WiMAX system to get better performance and mobility with higher data rate in image and video application. Standards from IEEE and ETSI have been used to develop this model. In this model, we have presented the paper built with generic MAC PDU processed by the Physical Layer using Convolutional Encoding Rate of ½ with QPSK modulation with image input.**

***Index Terms* -- BWA, IEEE 802.16, Wireless MAN, FEC, OFDM.**

I. INTRODUCTION

A broad industry consortium, the World wide interoperability for Microwave Access (WiMAX) Forum has begun certifying broadband wireless products for interoperability and compliance with a standard. WiMAX is based on wireless metropolitan area networking (WMAN) standards developed by the IEEE 802.16 group and adopted by both IEEE and the ETSI HIPERMAN group. In this paper, we present a concise technical overview of the emerging WiMAX solution for broadband wireless. The purpose here is to provide an executive summary before offering a more detailed exposition of WiMAX. We begin the chapter by summarizing the activities of the IEEE 802.16 group and its relation to WiMAX. Next, we discuss the salient features of WiMAX and briefly describe the physical and MAC-layer characteristics of WiMAX.

IEEE 802.16 Wireless MAN has a connection-oriented MAC and PHY is based on non-line of sight radio operation in 2-11 GHz. For licensed bands, channel bandwidth will be limited to the regulatory provisioned bandwidth divided by any power of 2, no less than 1.25MHz.Three technologies have been defined:

- single carrier (SC)
- orthogonal frequency division multiplexing (OFDM)
- orthogonal frequency division multiple access (OFDMA).

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

Standard	: IEEE 802.16e
Carrier Frequency	: Below I1IGHz
Frequency Bands	: 2.5GHz, 3.5GHz, 5.7GHz
Radio Technology	: OFDM and OFDMA
Bandwidth	: 1.5MHz to 20MHz
Data Rate	: 70 Mbps
Distance	: 10km

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 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.

II. 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: 1/2

The modelling setup includes Matlab R2006a, Simulink 6.5 and Communications Blockset 3 running on Windows vista. 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.

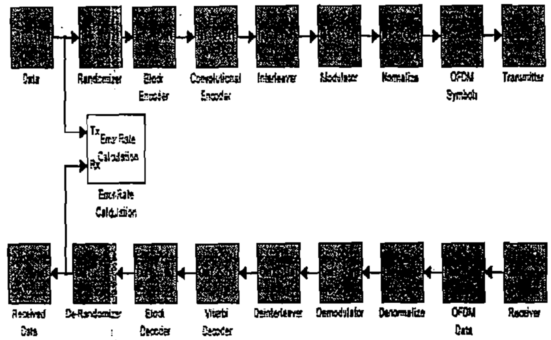

Figure 1 : WiMAX Physical Layer model

III. 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 radio link is a quickly varying link, often suffering from great interference. Channel coding, whose main tasks are to prevent and to correct the transmission errors of wireless systems, must have a very good performance in order to maintain high data rates. The 802.16 channel coding chain is composed of three steps: Randomiser, Forward Error correction (FEC) and Interleaving as shown in figure1. They are applied in this order at transmission. The corresponding operations at the receiver are applied in reverse order.

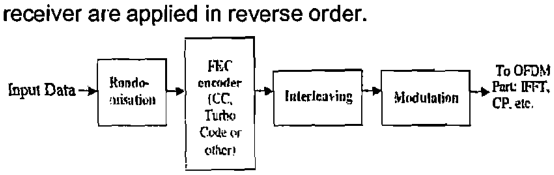

Figure 1: OFDM physical transmission channel

1) Randmization:

Randomisation introduces protection through information-theoretic uncertainty, avoiding long sequences of consecutive ones or consecutive zeros. It is also useful for avoiding non-centred data sequences. Data randomisation is performed on each downlink and uplink burst of data.

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

The Pseudo-Random Binary Sequence (PRBS) generator used for randomisation is shown in Figure 2.

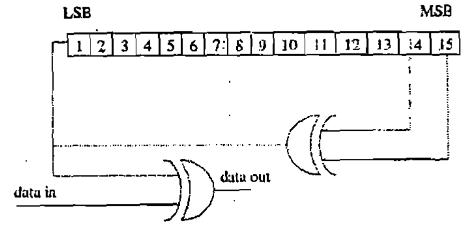

Figure 2 : Data Randomizer

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

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

The bits issued from the randomiser shall be applied to encoder.

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.

For OFDM PHY, the RS-CC encoding is performed by first passing the data in block format through the RS encoder and then passing it through a convolutional encoder (see Figure 3)

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.

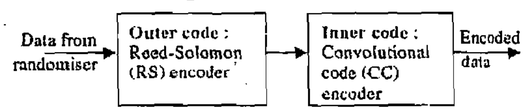

Figure 3 : Channel coding

A Reed–Solomon code is specified as RS(N,K) with T-bit symbols. The data points are sent as encoded blocks.The total number of T-bit symbols in an encoded block is $N = 2^T-1$. The number K, $K < N$, of uncoded data symbols in the block is a design parameter. Then, the number of parity symbols added is $N > K$ symbols (of T-bits each). The RS decoder can correct up to $(N - K)/2$ symbols that contain an error in the encoded block. WiMAX uses a fixed RS Encoding technique based on $GF(2^8)$ which is denoted as RS ($N = 255$, $K = 239$, $T = 8$).

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.

Where:

N = Number of Bytes after encoding

K = Data Bytes before encoding

T = Number of bytes that can be corrected

The following polynomial are used to generate systematic code:

Code generator polynomial:

$g(x) = (x - \lambda^0)(x - \lambda^1)(x - \lambda^2)\ldots(x \_ - \lambda^{2T-1}),\ \lambda = 02_{HEX}$; __(2)

Field generator polynomial:

$p(x) = x^8 + x^4 + x^3 + x^2 + 1$ ____(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 in-bit information symbol to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n > m) and the transformation is a function of the last k information symbols,

where k is the constraint length of the code.

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. In WiMAX Physical Layer each RS block is encoded by the binary convolutional encoder, which has a code rate of 1/2 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. One for each adder.

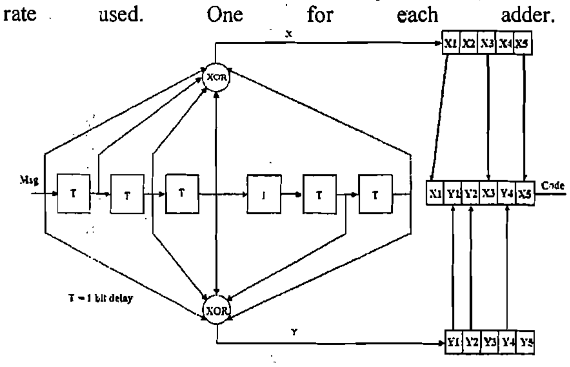

Figure 4 : FEC convolution and encoding

In WiMAX Physical Layer each RS block is encoded by the binary convolutional encoder, which has a code rate of 1/2 and a constraint length equal to 7. This encoder has two binary adders X and Y and uses two generator polynomials, A and B.

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IV. INTERLEAVING

RS-CC encoded data are interleaved by a block interleaver. The size of the block is depended on the numbers of bit encoded per subchannel in one OFDM symbol, Ncbps. In IEEE 802.16, the interleaver is defined by two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of unreliable bits.

The Matlab implementation of WiMAX 802.16 interleaver was performed calculating the index value of the bits after first and second permutation using Equation (7) and (8) respectively.

$f_k = (N_{cbps}/12).k_{mod12} + floor(k/2)$

$k = 0,1,2,\ldots..N_{cbps}-1$ ______(7)

$s_k = s.floor(f_k/s) + (m_k + N_{cbps} - floor(12.m_k/N_{cbps}))_{mod(s)}$

$k=0,1,2,\ldots\ \ldots.\ N_{cbps}-1$ _____(8)

where $s = ceil(N_{cpc}/2)$, while N_{cpc} stands for the number of coded bits per subcarrier, i.e.,1,2,4 or 6 for BPSK,QPSK 16QAM,or 64QAM, respectively.

The default number of subchannels i.e. 16 is used for this implementation. The receiver also performs the reverse operation following the two step permutation using equations (9) and (10) respectively.

$f_j = s.floor(j/s) + (j + floor(12.j/N_{cbps}))_{mod(s)}$

where $j=0,1,\ldots..N_{cbps}-1$ ____(9)

$s_j = 12.fj - (N_{cbps}-1).floor(12.fj/N_{cbps})$

where $j=0,1,2\ldots\ \ldots..N_{cbps}-1$ ____(10)

where:

N_{cpc} = Number of coded bits per carrier

N_{cbps} = Number of coded bits per symbol

K = Index of coded bits before first permutation

m_k = Index of coded bits after first permutation

j_k = Index of coded bits after second permutation

V. MODULATION

As for all recent communication systems, WiMAX/802.16 uses digital modulation. Four modulations are supported by the IEEE 802.16 standard: BPSK, QPSK, 16-QAM and 64-QAM. In this section the modulations used in the OFDM and OFDMA Physical layers are introduced for modulations. 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.

VI. OFDM SYSTEM IMPLEMENTATION

The digital implementation of OFDM system is achieved through the mathematical operations called Discrete Fourier Transform (DFT) and its counterpart Inverse Discrete Fourier Transform (IDFT). These two operations are extensively used for transforming data between the time domain and frequency domain. In case of OFDM, these transforms can be seen as mapping data onto orthogonal subcarriers. In practice, OFDM systems employ combination of fast fourier transform (FFT) and Inverse fast fourier transform (IFFT) blocks which are mathematical equivalent version of the DFT and IDFT.

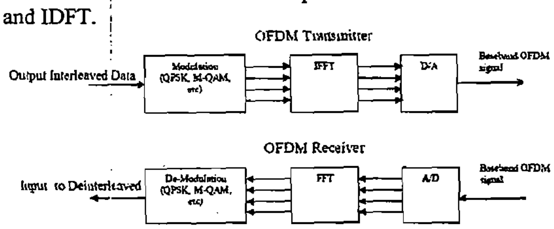

Figure 5 : Modulation and OFDM systems

At the transmitter side, an OFDM system treats the source symbols as though they are in the frequency domain. These symbols are feed to an IFFT block which brings the signal into the time domain. If the N numbers of subcarriers are chosen for the system, the basis functions for the IFFT are N orthogonal sinusoids of distinct frequency and IFFT receive N symbols at a time. Each of N complex valued input symbols determines both the amplitude and phase of the sinusoid for that subcarrier. The output of the IFFT is the summation of all N sinusoids and makes up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period. In this way, IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. At the receiver side, The FFT block performs the reverse process on the received signal and bring it back to frequency domain. The block diagram in Figure 5 depicts the switch between frequency domain and time domain in an OFDM system.

Cyclic Prefix Addition

The subcarrier orthogonality of an OFDM system can be jeopardized when passes through a multipath channel. CP is used to combat ISI and ICI introduced by the multipath channel. CP is a copy of the last part of OFDM symbol which is appended to the front of transmitted OFDM symbol.

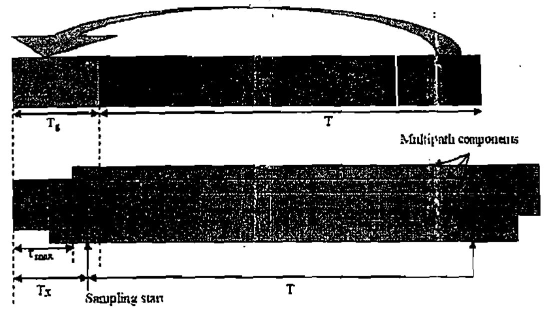

Figure 6 : Cyclic Prefix in OFDM

The length of the CP (T_g) must be chosen as longer than the maximum delay spread of the target multipath environment. Fig 6 depicts the benefits arise from CP addition, certain position within the cyclic prefix is chosen as the sampling starting point at the receiver, which satisfies the criteria $t_{max} < T_x < T_g$ where t_{max} is the maximum multipath spread. Once the above condition is satisfied, there is no ISI since the previous symbol will only have effect over samples within $[0, t_{max}]$. And it is also clear from the figure that sampling period starting from T_x will encompass the contribution from all the multipath components so that all the samples experience the same channel and there is no ICI.

VII. THE WIMAX MODEL TEST RESULTS

The WiMAX standard document 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 OF 55 28 AD 87 B5 76 IA 9C 80 50 45 IB 9F D9 2A 88 95 EB AE B5 2E 03 4F 09 14 69 58 OA SD

Data Frame after Randomization Stage (35 bytes frame)

D4 BA A1 12 F2 74 96 3027 D4 88 9C 96 E3 A9 52 B3 15 AB FD 92 53 07 32 CO 62 48 FO 19 22 E0 91 62 IA CI

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 9253 07 32 CO 62 48 FO 19 22 E0 91 62 1A C1 00

Data Frame after Convolutional Encoding (48 bytes frame)

3A SE E7 AE 49 9E 6F IC 6F Cl 28 BC BD AB 57 CD BC CD E3 A7 92 CA 92 C2 4D BC 8D 78 32 FB3 BF DF 23 ED 8A 94 16 27 AS 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 DB3 F9 B7 F13 43 6C FI 9A BD ED OA IC D8 IB EC 9B 30 15 BA DA 31 F5 50 49 7D 56 ED B4 88 CC 72 FC SC

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 taken as image input through WiMAX physical model for different Signal-to-Noise Ratios. Here we transmitting the image like 64 by 64 Check board Pattern (Monochrome) image and 256 by 256 Cameraman (Monochrome) image which is transmitted over WiMAX simulink physical model for various SNR values. As shown in figure 7 to 10, here for low and high SNR values we see the different result for both cases.

VIII. CONCLUTION

The model built in this paper demonstrates the importance of modelling a system to understand its functionality for image transmission and reception .Tests can the 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 image and video transmission and reception with security. In future this model can be expanded to include the components of security layer, MAC layer and a complete end to end WiMAX system could be built based on this model.

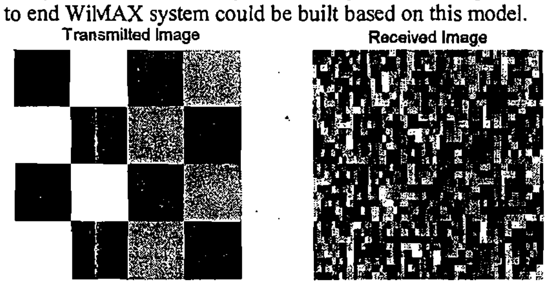

Figure 7: Application of image transmission through WiMAX simulink model for 64 by 64 Checkboard Pattern (Monochorome) image with lower SNR Value.

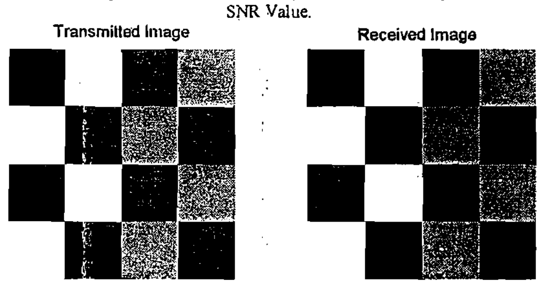

Figure 8 : Application of image transmission through WiMAX simulink model for 64 by 64 Checkboard Pattern (Monochorome) image with higher SNR Value.

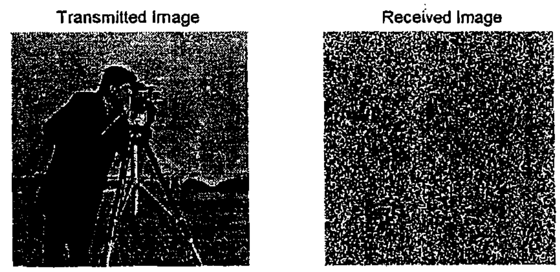

Figure 9: Application of image transmission through WiMAX simulink model for 256 by 256 Cameraman (Monochrome) image with lower SNR Value.

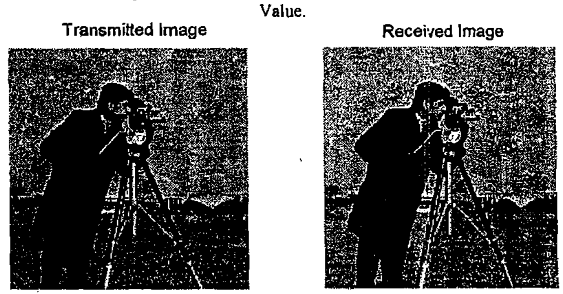

Figure 10: Application of image transmission through WiMAX simulink model for 256 by 256 Cameraman (Monochrome) image with higher SNR Value.

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