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Combined Effect of Block interleaving and FEC on BER Performance of OFDM based WiMAX (IEEE 802.16d) System

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Abstract In this World of Digital era the demand of mobile Internet and wireless multimedia applications are growing faster than ever. To satisfy the user requirements and to overcome the limitations of existing wireless technologies, have led the researchers to come up with more advanced and efficient technology. Orthogonal Frequency Division Multiplexing (OFDM) based WiMAX (Worldwide Interoperability for Microwave Access) is the outcome in this direction which promises to solve the last mile access technology to provide high speed internet access in the residential as well as small and medium sized enterprise sectors. In this paper we have analyzed the effect of Block Interleaving on the Bit Error Rate (BER) performance of the WiMAX Physical layer baseband system conforming to the parameters established by IEEE 802.16 standards for different digital modulation schemes. From the analysis it was observed that addition of interleaving with forward error correction (FEC) improves the system performance by reducing the burst errors during transmission.

Keywords: *BER, burst error, digital modulation, interleaving, FEC, OFDM, WiMAX*

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1. Introduction

WiMAX known as Worldwide Interoperability for Microwave Access is a wireless digital communications system designed to provide 30 to 40 megabit-per-second data rates, with the 2011 update providing up to 1 Gbit/s for fixed stations. It is also known as IEEE 802.16 that is intended for Wireless Metropolitan Area Networks (WMAN). WiMAX can provide broadband wireless access (BWA) typically 50 km for fixed stations, and 5 - 15 km for mobile stations. Whereas in contrast, the Wi-Fi/802.11 wireless local area network standard is limited in most cases to only 30 – 100 m. WiMAX is an IP based, wireless broadband access technology that provides performance similar to 802.11/Wi-Fi networks with the coverage and QOS (quality of service) of cellular networks. WiMAX can be used to provide a wireless alternative to cable and DSL for broadband access, and to provide high-speed data and telecommunications services.

WiMAX is based upon IEEE 802.16e-2005, approved in December 2005. It is a supplement to the IEEE 802.16-2004, and so the actual standard is 802.16-2004 as amended by 802.16e-2005. The original version of the standard on which WiMAX is based (IEEE 802.16) specified a physical layer operating in the 10 to 66 GHz range. 802.16a updated in 2004 to 802.16-2004, added specifications for the 2 to 11 GHz range. 802.16-2004 was updated by 802.16e-2005 in 2005 and uses scalable orthogonal frequency-division multiple access (SOFDMA) which is a method of encoding digital data on multiple carrier frequencies.

OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting. SOFDMA as opposed to the fixed orthogonal frequency-division multiplexing (OFDM) version with 256 sub-carriers (of which 200 are used) in 802.16d. More advanced versions, including 802.16e, also bring multiple antenna support through MIMO (multiple input multiple output). This brings potential benefits in terms of coverage, self installation, power consumption, frequency re-use and bandwidth efficiency. WiMAX is the most energy-efficient pre-4G technique among LTE and HSPA+.

The medium access control (MAC) and the physical (PHY) layers [8] have been included as the air interface defined by WiMAX standard. The MAC layer ensures efficient bandwidth usage by use of TDM/TDMA scheduled uplink/downlink frames. Since IEEE 802.16 supports ATM, IPv4, IPv6, Ethernet and Virtual Local

Area Network (VLAN) services therefore it can support a variety of high bandwidth broadband wireless applications such as Cellular Backhaul, Residential Broadband etc. The interoperability of WiMAX products are certified by WiMAX Forum, which was formed in June 2001 to promote conformity and interoperability of the standard. There are two version of the IEEE 802.16 standard [3] to provide different types of access which have been adopted by WiMAX Forum, one is IEEE802.16-2004 standard for fixed and nomadic access which uses OFDM to provide connection in Line of Sight (LOS) and Non Line of Sight (NLOS) environment and the other is IEEE 802.16e standard for Portable/Mobile Access which incorporates Scalable OFDM Access and provides solutions to handoffs and roaming. Table 1 below from the WiMAX Forum summarizes the 802.16 standards. In this work we have implemented the physical layer of fixed WiMAX and evaluated the Bit-Error-Rate (BER) performance using different guard time intervals.

Following this introduction the remaining part of the paper is organized as follows. Section II presents detailed description of physical layer of the WiMAX. In Section III the details of the modeling and simulation of the system using MATLAB is presented. Then Simulation results have been discussed in Section IV. Finally Section V provides the conclusion.

Table 1. IEEE Wimax standard for BWA [8]

WiMAX Standard & Completion year	IEEE 802.16 Dec 2001	IEEE 802.16a Jan 2003 & Revised in 2004	IEEE 802.16e-2005
Modulation Type	BPSK, QPSK 16-QAM 64-QAM	QPSK 16-QAM 64-QAM	QPSK 16-QAM 64-QAM
Spectrum Allocated	10-66 GHz	2-11 GHz	2-6 GHz
Duplex type	TDD/FDD	TDD/FDD	TDD/FDD
Bandwidth range	1.25 to 28.0 MHz	1.25 to 28.0 MHz	1.25 to 28.0 MHz
Bit Rate	Up to 134 Mbps	Up to 75 Mbps	Up to 15Mbps
Propagation/channel conditions	LOS	NLOS	NLOS
Mobility	Fixed	Fixed	Fixed/Nomadic (Pedestrian Mobility)
Guard period	1/4, 18, 1/16, 1/32	1/4, 18, 1/16, 1/32	1/4, 18, 1/16, 1/32
FFT size	-	256	128, 256, 512, 1024, 2048
MIMO	Yes [2X2]	Yes[2X2]	Yes[2X2]
aerA egarevoC	1 to 3 miles	3 to 5 miles, Max. 30 miles depending upon antenna gain and transmitted power	1 to 3 miles

Table 2. WiMAX OFDM PhyParameters

Parameter	Fixed WiMAX OFDM-PHY	Mobile WiMAX Scalable OFDMA-PHY
FFT size (N_{FFT})	256	128 512 1,024 2,048
Number of data subcarriers	192	72 360 720 1,440
Number of pilot subcarriers	8	12 60 120 240
Number of null/guard subcarrier	56	44 92 184 368
Guard Time (Tg)	1/4	1/32, 1/16, 1/8,1/4
Channel bandwidth (MHz)	3.5	1.25 5 10 20
Subcarrier frequency spacing, Δf (kHz)	15.625	10.94
Useful symbol time Tb(μs)	64	91.4
OFDM symbol duration Ts(μs)	72	102.9

2. IEEE 802.16 WiMAX PHY Layer

This section discusses about the OFDM based IEEE 802.16 PHY layer which can be used in conjunction with the MAC layer to provide a reliable end-to-end link.

Orthogonal Frequency-Division Multiplexing (OFDM) is the key development in the WiMAX PHY layer that makes it resistant to multipath fading effects and inters symbol interference (ISI). Addition of cyclic prefix is the key operation for ISI removal. OFDM is derived from the fact that the high serial bit stream data is transmitted over large (parallel) number sub-carriers (obtained by dividing the available bandwidth), each of a different frequency and these carriers are orthogonal to each other. OFDM converts frequency selective fading channel into N flat fading channels, where N is the number of sub-carriers. Othogonality is maintained by keeping the carrier spacing multiple of 1/Ts by using Fourier transform methods, where Ts is the symbol duration. Since channel coding is applied prior to OFDM symbol generation which accounts for the term ‘coded’ in COFDM. Figure 1 below presents the detailed block diagram of an OFDM Transceiver.

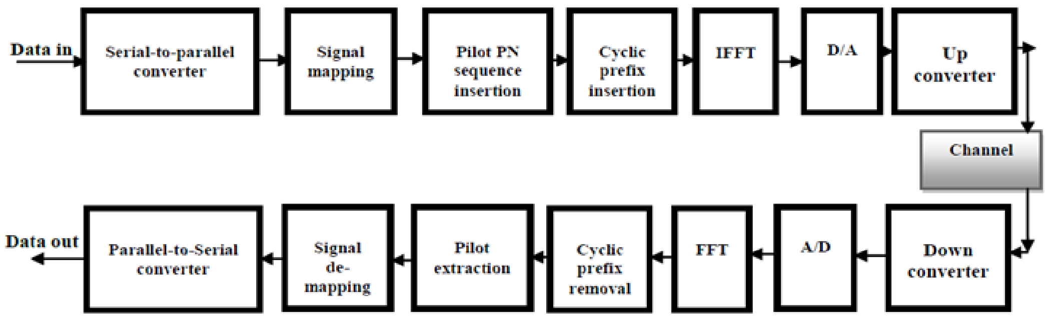

Figure 1. Block diagram of an OFDM Transceiver

2.1. Fixed WiMAX OFDM-PHY

This is based on 256-point Fast Fourier Transform (FFT) OFDM multiplexing scheme in which 192 subcarriers used for carrying data, 8 used as pilot subcarriers for channel estimation and synchronization purposes, and the rest 56 used as guard band subcarriers. This PHY is for 2-11 GHz frequency band and uses TDD mode of access. The channel bandwidth can be an integer multiple of 1.25 MHz, 1.5 MHz, 1.75 MHz, 2MHz and 2.75 MHz with a maximum of 20 MHz. Forward Error Correction (FEC) is done on two phases through the outer Reed-Solomon (RS) code and inner Convolutional code (CC). The RS coder corrects burst error at the byte level. It is particularly useful for OFDM links in the presence of multipath propagation. The CC corrects independent bit errors [8].

2.2. Mobile WiMAX OFDM-PHY

This is based on 2048-point FFT OFDMA scheme but the FFT size can vary from 128 to 2,048. Here, when the available bandwidth increases, the FFT size is also increased to keep the subcarrier spacing always 10.94 kHz [8]. A scalable design also keeps the costs low. This PHY is below 11 GHz frequency band. The details of Parameters for both the IEEE 802.16 PHY layer is shown in Table 2.

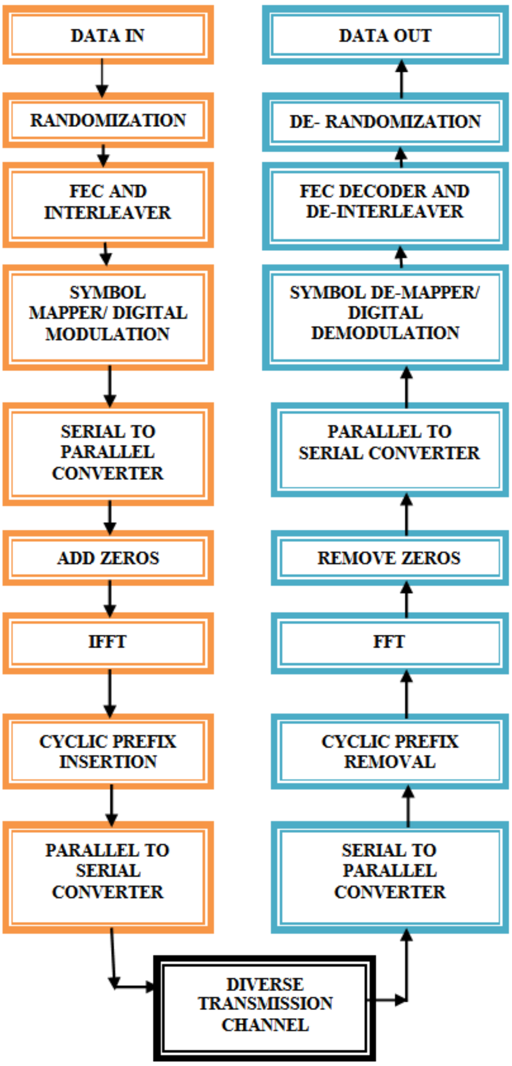

Figure 2. Simulation model of WiMAX-PHY layer

3. Simulation Model

This section discusses the simulation model implemented by us in MATLAB 8.0 environment to evaluate BER performance analysis of IEEE 802.16 OFDM based WiMAX system having 20 MHz bandwidth conforming to the parameters as specified in Table I and II. The functional blocks of baseband WiMAX transceiver is depicted in Figure 2. In the transmitter part the data from the source is randomized first and then subjected to forward error correction (FEC) Encoder employing punctured convolutional codes with code rate 1/2. The coded data is then Block interleaved and mapped into QPSK/QAM symbols. Previously, multi-carrier systems were implemented through the use of separate local oscillator. This was both inefficient and costly. With the advent of cheap powerful DSP processors, the sub-carriers can now be implemented by the fast Fourier transform algorithms (FFT) which keep sub-carriers orthogonal with each other. The symbol is modulated onto sub carriers by applying the Inverse Fast Fourier Transform (IFFT). The output is converted to serial data and a cyclic prefix of $\frac{1}{32}$ is added to make the system robust to inter-symbol interference (ISI). In channel, additive white Gaussian noise characteristics are taken along with the fading Rayleigh channel. The receiver performs the reverse operations of the transmitter. The important blocks of the simulation model is discussed in detail as follows:

3.1. Randomizer

To avoid long sequence of continuous ones and zeros the information bits is randomized before the transmission. This ensures appropriate energy dispersal in the transmitted signal minimize the possibility of transmissions of non-modulated sub carriers. This is implemented with a Pseudo Random Binary Sequence (PRBS) generator which uses a 15-stage shift register with a generator polynomial of $1 + x^{14} + x^{15}$ with XOR gates in feedback configuration as shown in Figure 3.

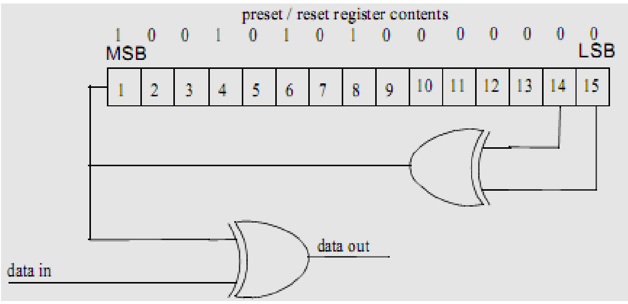

Figure 3. Randomizer [3]

3.2. FEC Encoder

This block consists of a concatenation of an outer Reed Solomon (RS) code and an inner convolutional code (CC) as a FEC scheme. The last block of the encoder is an interleaver to avoid long burst errors. The RS encoder implemented is a systematic RS (N=255, K=239, T=8) code using Galois field GF (28), where N is the number of bytes after encoding, K is the number of data bytes before encoding and T is the number of bytes which can be corrected.

After the RS encoding process, the data bits are further encoded by a binary Convolutional encoder, which has a mother code rate of $\frac{1}{2}$ and a constraint length of 7. The generator polynomials used to derive its two output code bits, denoted X and Y, are $G1 = 171_{OCT}$ & $G2 = 133_{OCT}$ respectively. This convolutional encoder is shown in Figure 4.

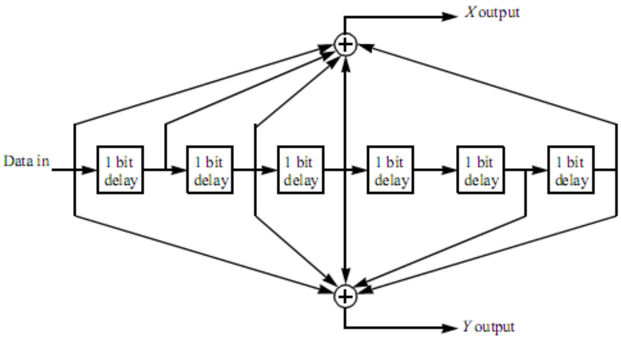

Figure 4. Convolutional Encoder of mother code rate $\frac{1}{2}$ [3]

3.3. Block Interleaving

Data interleaving is performed prior to symbol mapping to scatter burst errors so that it converts in few scarcely spaced single symbol errors, which are more easily correctable, thereby increasing the efficiency of FEC. The RS-CC encoded data are interleaved by a block interleaver whose block size corresponds to the number of coded bits per the allocated sub channels per OFDM symbol, N_{cbps}.

In IEEE 802.16 standard [3], the interleaver is defined by two step permutation. The first ensures that adjacent coded bits are mapped onto non-adjacent 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 index value of the bits after first and second permutation will be calculated using following Equation (1) and (2) respectively.

$$x_k = \left(N_{cbps}/12\right).k_{\text{mod}12} + floor\left(k/2\right) \quad (1)$$

where $k = 0,1,2,\dots\dots N_{cbps} - 1$, known as the index of the coded bit before the first permutation.

$$y_k = s.floor\left(x_k/s\right) + \left(m_k + N_{cbps} - floor\left(12.m_k/N_{cbps}\right)\right)_{\text{mod}(s)} \quad (2)$$

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

3.4. Digital Modulation Mapper

After channel coding and interleaving data are then entered serially to the digital modulation mapper that support BPSK, grey-mapped QPSK, 16-QAM, and 64-QAM as specified in the standard [3]. The bits are mapped to a subcarrier amplitude and phase, which is represented by a complex in-phase and quadrature-phase (IQ) vector. The IQ plot for a modulation scheme shows the transmitted vector for all data word combinations. Gray coding has been used for this allocation so that adjacent points in the constellation only differ by a single bit. This coding helps to minimize the overall bit error rate as it reduces the chance of multiple bit errors occurring from a single symbol error [10]. The constellation plots for BPSK, 4-QAM, and 16-QAM modulations are depicted in Figure 5.

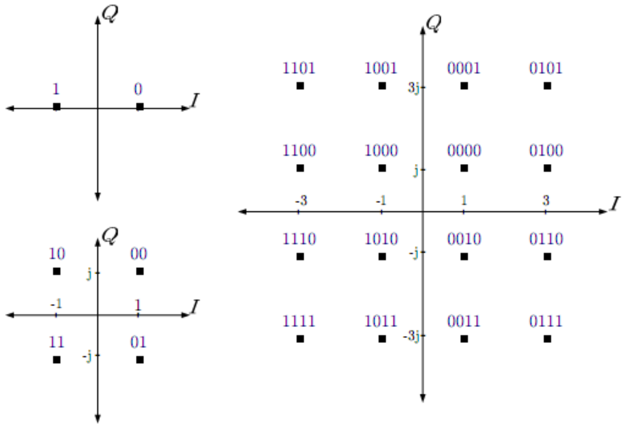

Figure 5. BPSK, 4-QAM, and 16-QAM constellation diagrams [10]

3.5. Channel

Finally to evaluate the performance of the developed WiMAX communication system, the transmitted signal is exposed to six different types of channel conditions [8,10] which are three paths fading channels. The wireless channel designed use

Multipath delay spread, Fading characteristics, Doppler spread, the effect of Path loss (including shadowing), Co channel and adjacent channel interference.

4. Result and Discussion

In this section we have presented the simulation results along with the bit error rate (BER) curve analysis for Rayleigh and Rician three path fading channel. The simulation parameters for WiMAX system are as per Table 1 and Table 2. This section gives the effect of bit interleaving on the performance of different digital modulation.

Figure 6 and Figure 7 below, presents the BER performance improvement due to bit interleaver for BPSK modulation on channel 1 and channel 2.

It can be seen from these BER curves that inclusion of bit interleaver helps FEC to work properly. It can evaluated from the Figure 6 and Figure 7 that bit there is a interleaver-coding gain of 5 dB at BER level of 10^{-4} on channel 1 and 10.3 dB SNR improvement on channel 2.

After analyzing effect of interleaver for BPSK modulation, we will now investigate the performance improvement for QPSK, 16QAM and 64QAM on the same channel conditions, as depicted from Figure 8 to Figure 13 below. The SNR improvement observed from these all figures are tabulated in Table 3.

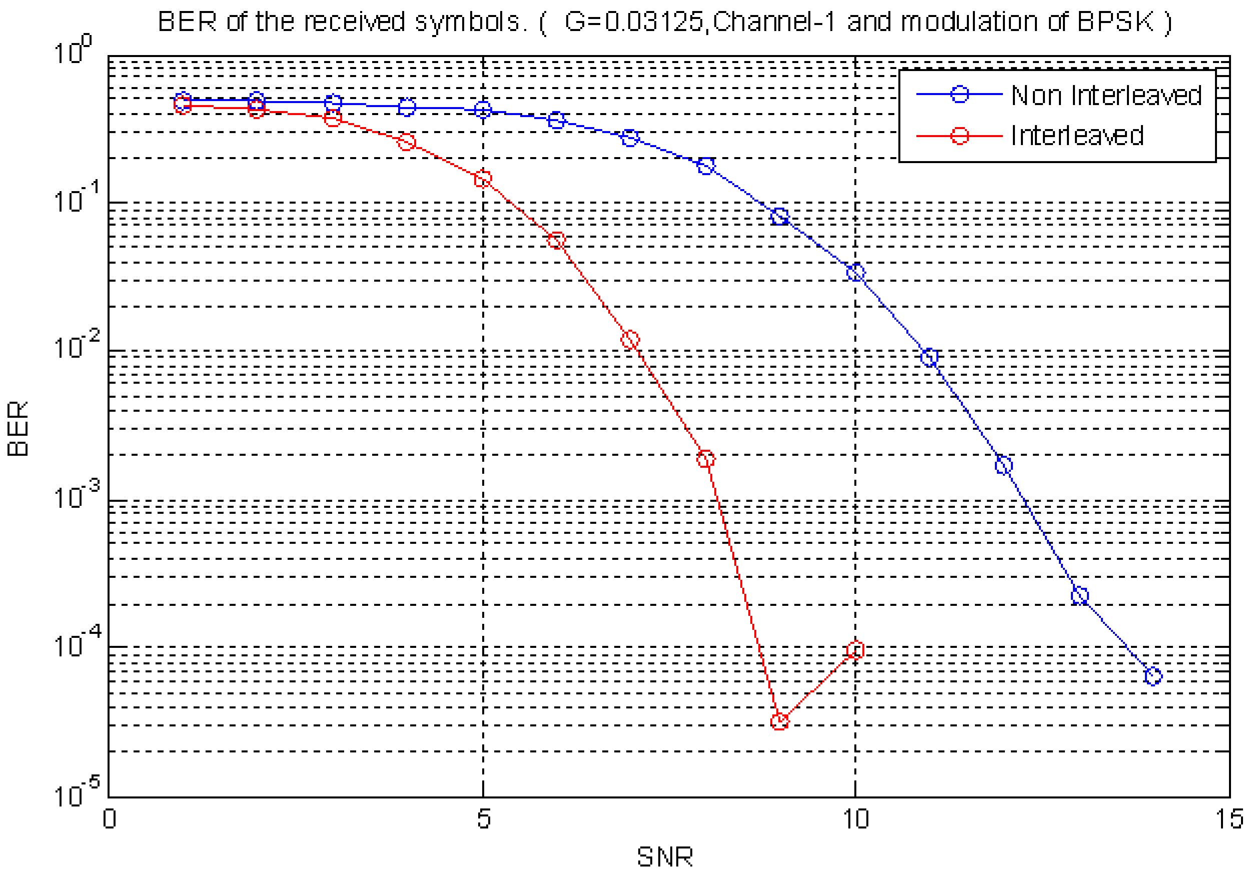

Figure 6. Effect of Block interleaver in BPSK on Channel-1

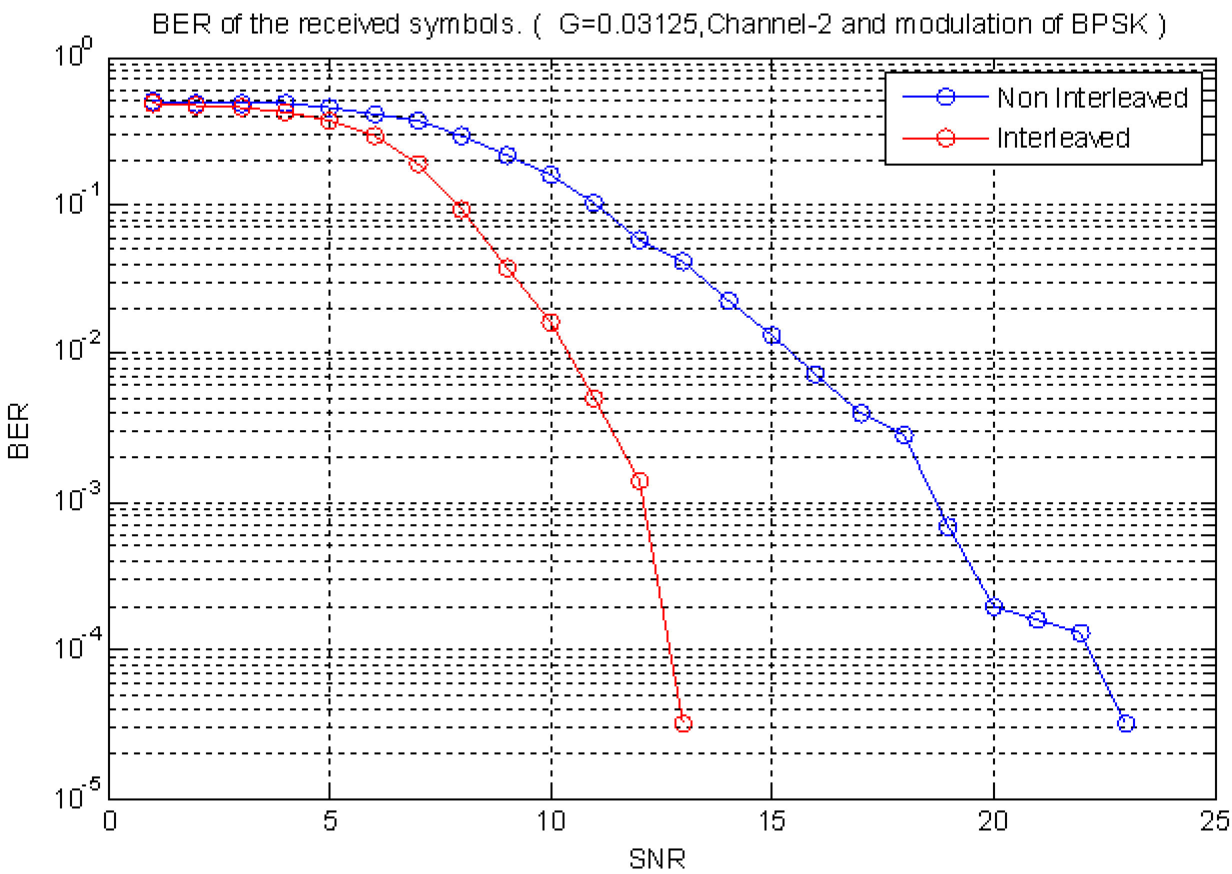

Figure 7. Effect of Block interleaver in BPSK on Channel-2

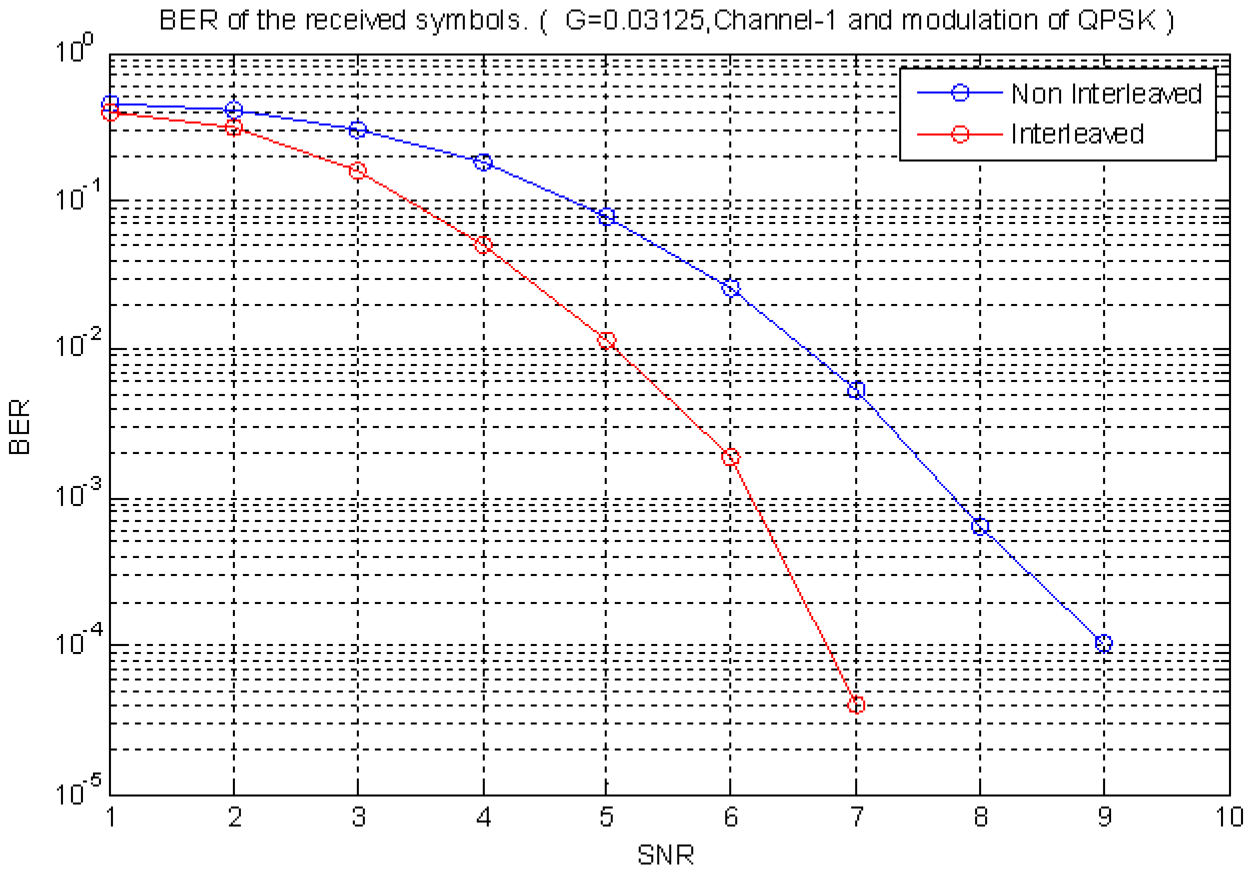

Figure 8. Effect of Block interleaver in QPSK on Channel-1

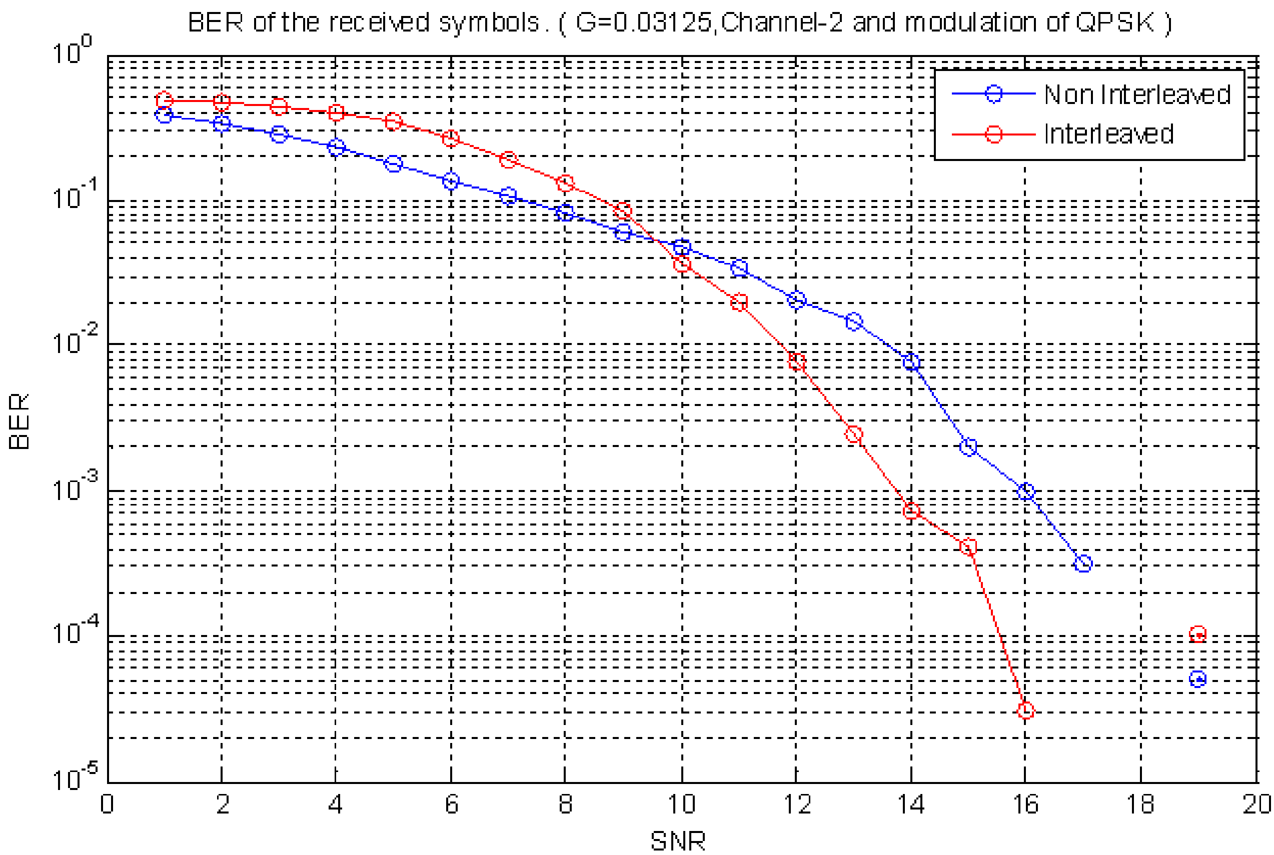

Figure 9. Effect of Block interleaver in QPSK on Channel-2

Table 3. Performance improvement due to block interleaving

Modulation	BPSK		QPSK		16QAM		64QAM	
	Channel 1	Channel 2	Channel 1	Channel 2	Channel 1	Channel 2	Channel 1	Channel 2
Coding gain (dB) at BER 10^{-4}	5	10.3	3.2	2.5	1.9	1.8	2.4	3

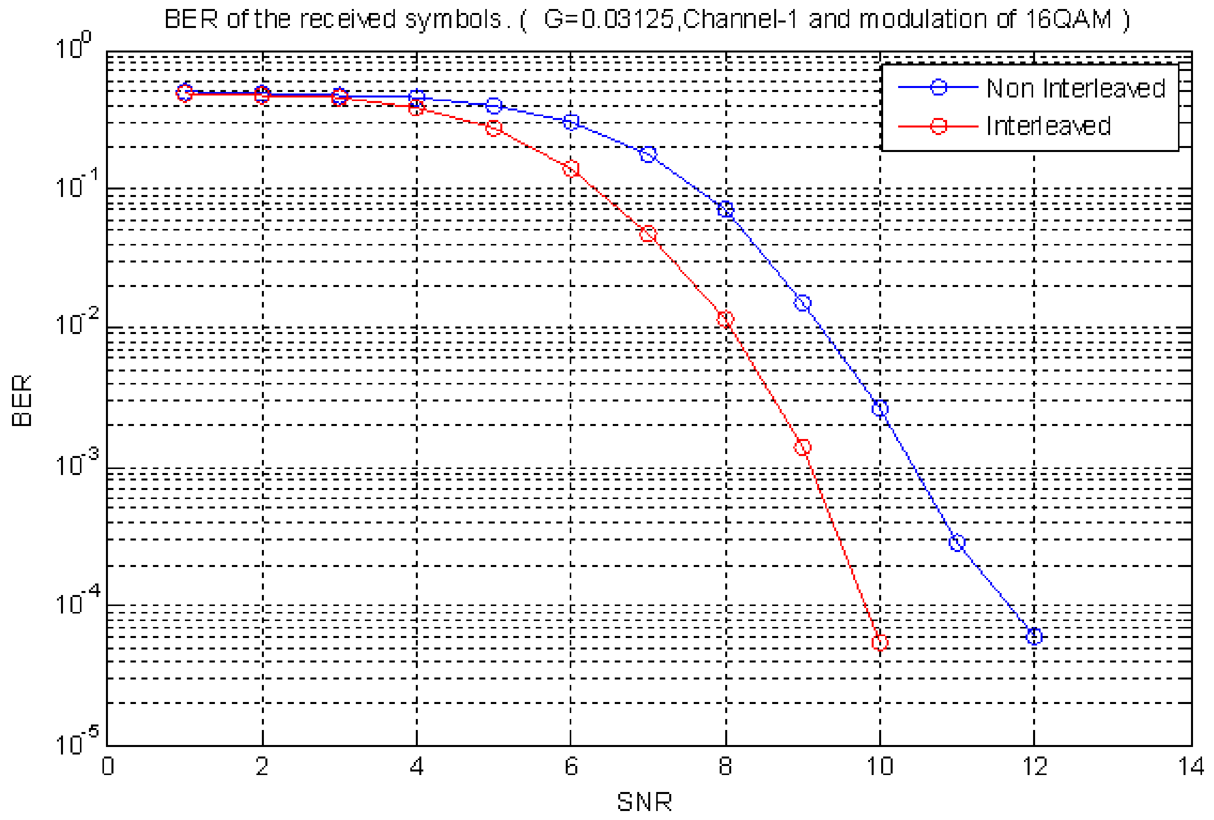

Figure 10. Effect of Block interleaver in 16-QAM on Channel-1

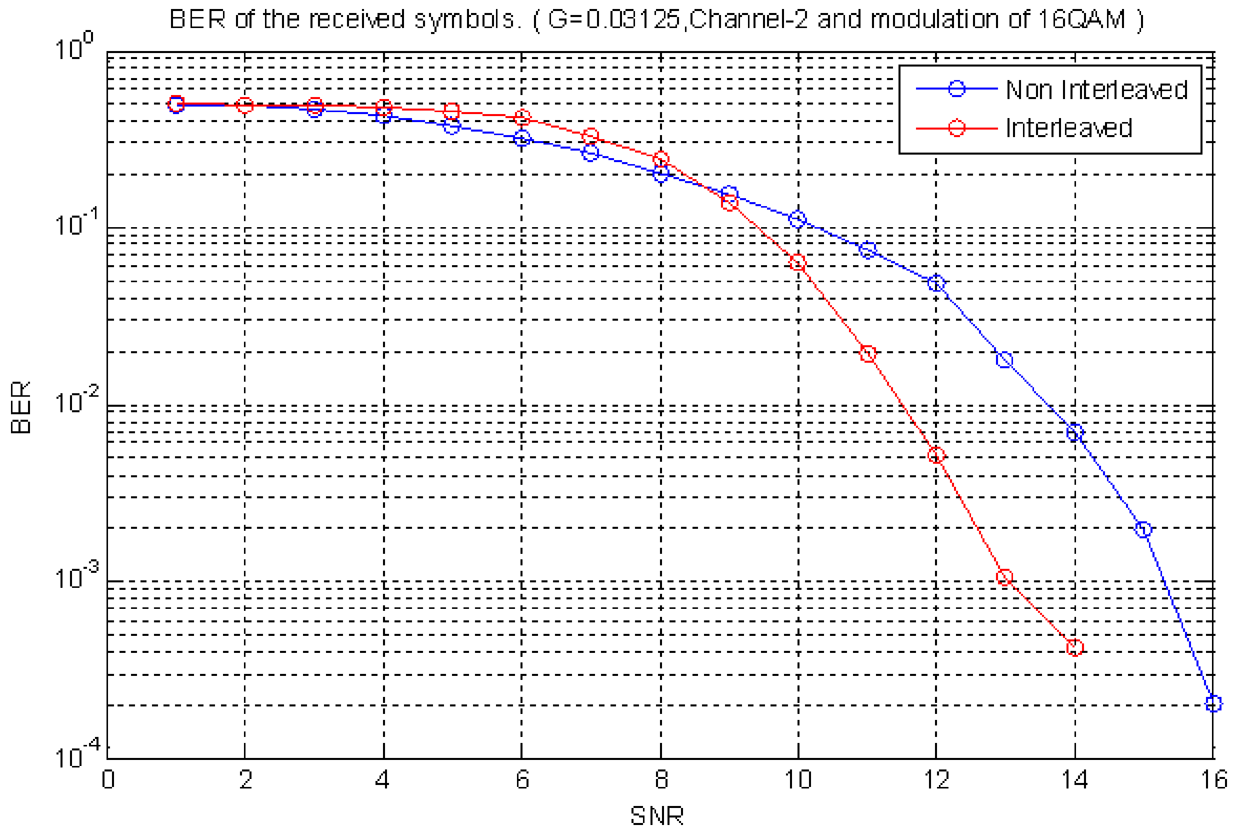

Figure 11. Effect of Block interleaver in 16-QAM on Channel-2

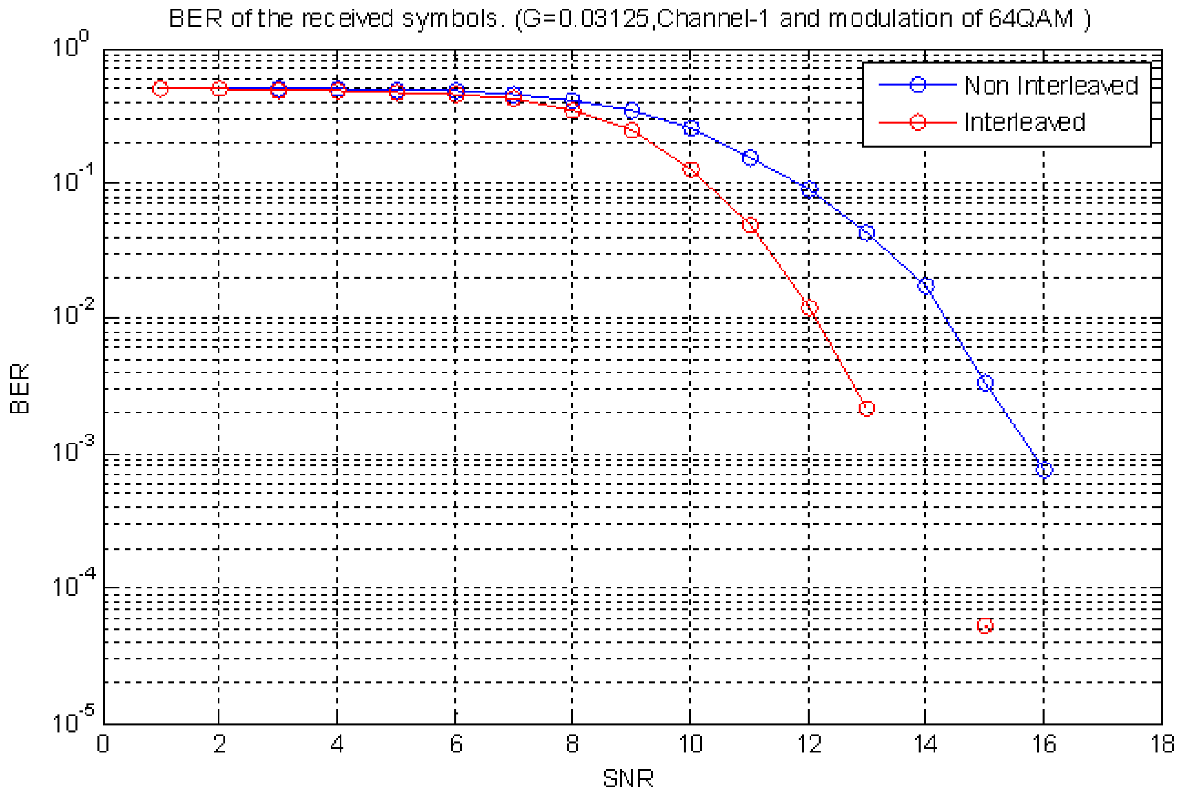

Figure 12. Effect of Block interleaver in 64-QAM on Channel-1

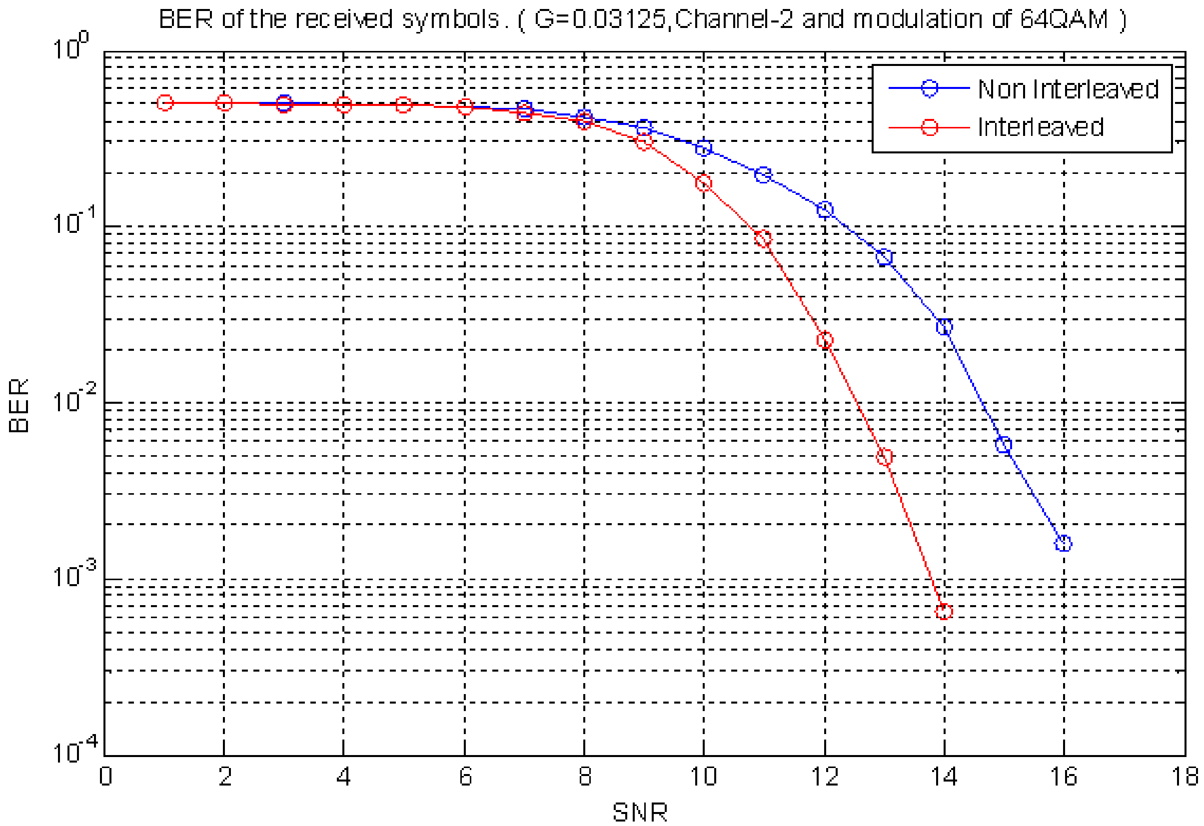

Figure 13. Effect of Block interleaver in 64-QAM on Channel-2

5. Conclusion

The key contribution of this paper was the implementation PHY layer of IEEE 802.16 OFDM based WiMAX system to evaluate the effect of block interleaver on the BER performance. It was shown clearly that interleaver improves the performance of the WiMAX system. Use of interleaving techniques increases latency which should be taken care when designing the communication system. The work can be successfully extended with addition of other interleaving techniques such as convolutional interleaving, frequency interleaving for further improvement in performance.

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