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Performance Assessment of WiMAX using Diverse FEC Schemes over Fading Channels

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Abstract

Diverse modern wireless broadband communication systems are based on what is called Orthogonal Frequency Division Multiplexing (OFDM), which is a basic part of WiMAX. By making use of OFDM, we deal with frequency and time selectivity which are the major concerns when mobile or wireless communication is established between base and subscriber stations. WiMAX cuts the cost because it's a wireless technology and hence there is little maintenance. Also, it provides higher data rates and has large coverage area compared to its counters parts. In this paper, we make a comparison of various channel coding techniques like convolutional codes, BCH codes, LDPC codes and RS codes over two fading channels namely Rayleigh channel and Rician channel and four modulation orders of PSK. The simulation results show that RS codes and BCH codes perform very well in all conditions whereas convolutional codes lag somewhat in their performance. In addition to this, Rician channel has a better response compared to Rayleigh channel in any modulation order or FEC codes being used in a WiMAX system.

Keywords: BCH, BER, FEC, LDPC, RS, WiMAX

1. Introduction

WiMAX stands for Worldwide Interoperability for Microwave Access. The basic building block of WiMAX is OFDM, which helps in transmitting signals orthogonally making good use of bandwidth and helps in reduction of ISI. It also helps to deal with signal degradation due to multipath loss and shadowing. Mathematically orthogonality in signals is achieved by performing Fast Fourier Transform (FFT). It is because of FFT signals are transmitted with overlapping and are processed well at the receiver without losing the actual characteristics[1]. It's a WMAN and makes use of both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). It has many variants including LOS and NLOS type. The channel in mobile communication is mostly fading channels whose characteristics vary with time and distance. These channels cannot be predicted beforehand, but an approximation can be taken based on Rayleigh and Rician distributions. Rayleigh distribution is used when there is no line of sight component present in the received signal whereas Rician distribution is used when there is some line of sight component which is strong compared to other received signals[2]. WiMAX is also referred to as 4G technology because it has a range of up to 35 km and a data rate of up to 70 Mbps. It makes use of forward error correction schemes which helps in detection and correction of errors that occur during the transmission.

The interleaver can be used in addition to FEC block to overcome burst errors, which are long series of errors during a deep fade. The opposite blocks have to be used at the receiver side to invert the processes at the transmitter side[3]. Earlier, we used ARQ for errors or signaling missing packets or data and it used the reverse channel for requesting retransmission. Nowadays, we use FEC schemes, where calculated redundancy is added to the data at transmitter and errors are detected and corrected at the receiver side effectively[4]. There is various error correcting codes like convolutional codes, RS codes, BCH codes and LDPC codes, etc. These codes work accord-

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ing to the block diagram is given in Figure 1. The various codes differ from each other in their applications and difficulty of implementation. BCH codes can be used to a WiMAX system. These form a sub category of cyclic codes which is mainly used in storage devices and satellite communication systems. RS (Reed-Solomon) codes further are a sub class of BCH codes. The difference between the two is that for BCH codes the error locator and code fields are different whereas it's the same for RS codes[5,6].

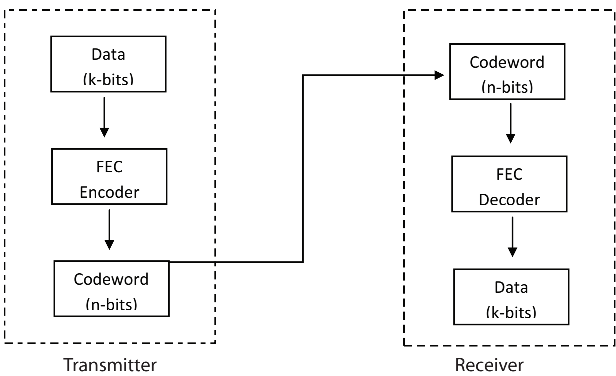


Figure 1. Forward error correction block diagram.

A diverse combination of codes called product code to improve further the performance of a system like the concatenated Reed-Solomon Convolutional Codes (RS-CC) can be used. With this combination of codes, the wireless communication system performance can be improved by orders of magnitude. Its BER performance is also better[7,8]. Another combination of codes can be RS-LDPC codes which can also improve the performance of a WiMAX system and is also rate compatible which means it adapts to the code rate according to the channel conditions. Its simple to implement with both hard and soft decision decoding. The LDPC codes used should be raptor based for this kind of implementation[9,10]. With growing demand for wireless communication systems, there was the evolution of WiMAX, which is the fourth generation communication system that enables large coverage and high data-rates, both at the line of sight and non-line of sight transmissions[11,12]. This paper gives an overview of WiMAX physical layer simulation in various fading channels and using different channel codes.

2. Block Description of WiMAX System

WiMAX technology is a rapidly growing broadband wireless technology, which has been transmitted on both – Line Of Sight (LOS) and Non-Line Of Sight (NLOS). The operating bands of WiMAX system range between (2-11) GHz range for LOS and (10-66) GHz range for NLOS. The distance covered by LOS is (2-5) km and NLOS is (5-50) km. WiMAX can be either fixed - IEEE 802.16 or mobile – IEEE 802.16e. The block description of WiMAX physical layer is very diverse. It consists of various blocks which work in conjunction with each other. The block diagram is given in Figure 2.

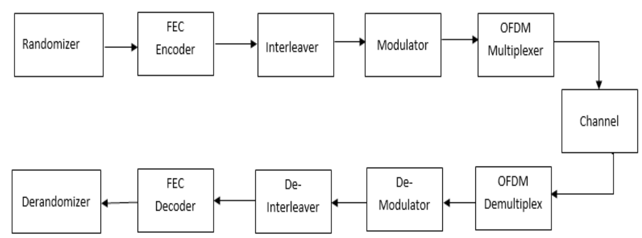


Figure 2. Block description of WiMAX physical layer.

2.1 Randomizer and De-Randomizer

Randomizer block is used to make a random distribution of data bursts. It always works on the block of data called bursts. It makes use of pseudo random bit generator which is made of shift registers. The block diagram of randomizer is given in Figure 3. At the receiver side, we have a reverse process to undo the randomization done at the transmitter side called De-Randomizer.

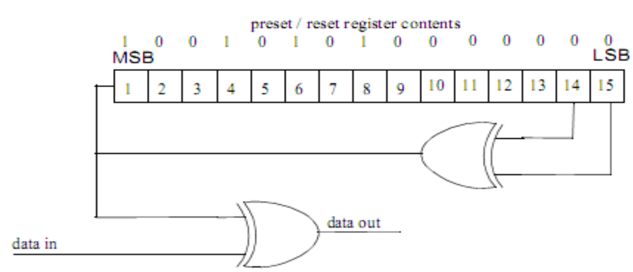


Figure 3. Randomizer.

2.2 FEC Encoder and FEC Decoder

This block is one of the most important blocks of WiMAX because its dramatically affects the performance of the system. The FEC encoder block diagram is shown in Figure 1. The input to this block is of 'k-bits' and the output is of 'n-bits', where n>k. This addition of bits is done by FEC block in an ordered way which is used at the receiver side to detect and correct the errors. There are various FEC schemes that are being used, the four of those which are used in this paper are discussed below:

- **BCH Codes:**

BCH codes were discovered by three scientists Bose, Chaudhuri and Hocquenghem and are named after them only. This channel coding technique is one of the most powerful coding techniques. It falls in the category of cyclic codes. Since they are a type of cyclic codes they can be encoded and decoded in the same way or we can also use some different and easy encoding and decoding methods. These codes are different from previously developed codes because earlier we first used to construct the code and then find out its minimum distance to see how many errors it can detect and correct. In this coding technique, we first figure out how many errors we want this code to detect and correct and then accordingly design a generator polynomial for it.

- **Convolutional Codes:**

Convolutional codes are another category of channel codes used to detect and correct errors. It makes use of shift registers for encoding and decoding because they provide memory. In these codes, memory is required because we need previous bits as well as current bits to make a code word out of a message. At the receiver side, we use a Viterbi decoder to decode the encoded data. The decoding can be both hard decision decoding or soft decision decoding. Viterbi decoding is a maximum likelihood decoding based on finding the shortest path in the trellis diagram.

- **LDPC Codes:**

LDPC stand for Low-Density Parity Check Codes. They were discovered by R. Gallager in 1962. They did not gain much of popularity back then but are very popular nowadays because they are one of the best error correcting codes. They make use of a parity check matrix which is sparse in nature; that is, it has very few number of ones and a large number of zeros. There are various algorithms to decode the LDPC codes like bit flipping algorithm, message passing algorithm, etc. LDPC codes are often represented by a tanner graph which is a bipartite graph having two types of nodes-bit nodes and check nodes. It is a graphical representation of parity check matrix (H).

- **RS Codes:**

RS codes stand for Reed-Solomon codes after the names of the scientists who discovered these codes. Reed-Solomon codes are like BCH codes a class of cyclic codes. They are used in many digital communication applications like storage devices, digital television, wireless communication and can be used efficiently in WiMAX as well. In this coding rather than taking individual bits, a group of data says bytes are taken which makes this coding scheme different from others. Since groups of bits are taken it can overcome burst errors which are difficult to remove otherwise. So, it can cope up with thousands of consecutive erroneous bits.

At the receiver side, we have FEC decoder block which removes the redundancies added at the transmitter side. It detects any errors and corrects them and then gets the data in the original form as was transmitted.

2.3 Interleaver and De-Interleaver

Interleaver is used to overcome very long sequences of errors or burst errors. Interleaver does the permutation of bits or reordering. There are various types of interleavers also. One of the interleavers is block interleavers, whose principle is to write row-wise and read column-wise. At the receiver, a reverse process is used where data is written column-wise and read row-wise. Other types of interleavers are convolutional interleaver and random interleaver. Interleavers help to overcome deep fades in the signal transmission.

2.4 Modulator and Demodulator

The modulator is used as an interface between channel and interleaver which helps to map digital data in signal waveforms so that it can be transmitted well on the channel. The modulation schemes may be based on amplitude, phase or frequency. The modulations used in this paper are sub-types of PSK (Phase Shift Keying). In PSK, the phase of the carrier by with the information signal. In this paper, we have used four different orders of PSK (2, 4, 16 and 64). This determines the number of bits that forms one signal or symbol. Higher, the order of modulation higher, is the probability of error. At the receiver side, we have demodulator which demodulates the signal waveform to digital data.

2.5 OFDM Multiplexer and Demultiplexer

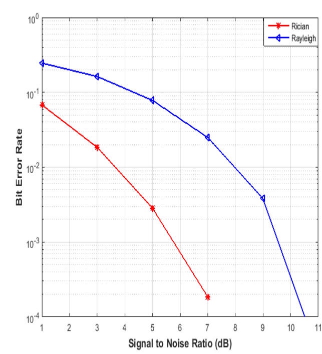
OFDM multiplexer is used for orthogonal frequency division multiplexing. Its function is to divide carriers into sub-carriers which are orthogonal to each other so that they do not cause inter-symbol interference. This is mathematically implemented by using IDFT or IFFT on the transmitter side and DFT or FFT at the receiver side. The time duration is called as the useful symbol time 'T_b'. A copy of the previous 'T_g' μs of the useful symbol called Cyclic Prefix (CP) is appended to useful data. It prevents interference between the symbols. The resulting time is called the symbol time 'T_s'.

2.6 Channel

Channel is the medium over which the signal is transmitted. For wireless communication, air is the medium. The channel used in this paper is Rayleigh channel and Rician channel. Both are fading channels which have varying characteristics with respect to time and are random in nature. The difference between the two is that Rayleigh channel has no line of sight whereas Rician channel has atleast one dominant line of sight path.

3. Simulation Results

The results of the simulation for a WiMAX system for four channel codes and four modulation orders of PSK are given in figures below. For each graph, we have evaluated BER versus SNR for two fading channels namely - Rayleigh and Rician channels. In Figure 4(a), the BER of WiMAX system using BPSK and BCH codes is shown for both channels. It shows that for a BER of 10^{-3}, SNR required for Rician channel is about 5.7 dB and SNR required for Rayleigh channel is 9.5 dB. There is an SNR improvement of about 3.8 dB. If we see Figure 4(b), which shows BER of WiMAX system using QPSK and BCH codes in the mentioned fading channels, we can see that for a BER of 10^{-3} Rician channel requires an SNR of 5.8 dB and Rayleigh channel requires an SNR of 8.2 dB. For this case, there is an SNR improvement of about 2.8 dB in Rician channel. We have a WiMAX system using 16-PSK and BCH codes in Rayleigh and Rician channels shown in Figure 4(c). For a BER of 10^{-3}, Rician channel requires an SNR value of 7.8 dB and Rayleigh channel requires an SNR of 13.5 dB. The improvement in SNR is about 5.7 dB in Rician channel compared to another channel. BER versus SNR graph for a WiMAX system using 64-PSK and BCH codes has been shown in Figure 4(d). For a BER of 10^{-3}, Rician channel must have an SNR of 15 dB and Rayleigh Channel must have an SNR of 20.3 dB. From this, we can see an SNR progress of about 5.3 dB in the case of Rician channel over Rayleigh channel. In Figure 5(a), we have the BER of WiMAX system using BPSK modulation and convolutional codes which show that for a BER of 10^{-3}, SNR required for Rician channel is about 4.5 dB and SNR required for Rayleigh channel is 8.5 dB. There is an SNR improvement of about 4 dB. We have BER versus SNR graph of WiMAX system using QPSK modulation and convolutional codes in Figure 5(b). In this figure, we can see that for a BER of 10^{-3}, Rician channel necessities an SNR of 6.5 dB and Rayleigh channel necessities an SNR of 12.3 dB, that is, there is an SNR improvement of about 5.8 dB in the case of Rician channel. In Figure 5(c), we have a WiMAX system using 16-PSK modulation and convolutional codes in Rayleigh and Rician channels. To get a bit error rate of 10^{-3}, Rician channel must have an SNR value of 10.4 dB and at the same time, Rayleigh channel requires an SNR of 16.3 dB for the same showing an improvement in SNR of about 5.9 dB in Rician channel over the Rayleigh channel. If we have a look at the next figure, we have the BER versus SNR graph for a WiMAX system using 64-PSK and convolutional codes. For a BER of 10^{-3}, Rician channel requires an SNR of 18.4 dB and Rayleigh channel requires an SNR of 24 dB. SNR has improved of by 5.6 dB in the case of Rician channel over another fading channel as shown in Figure 5(d).



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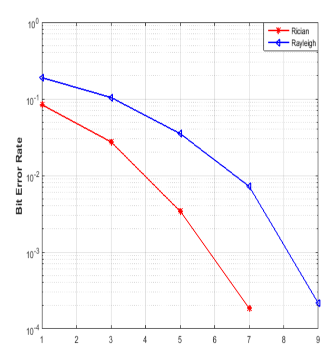

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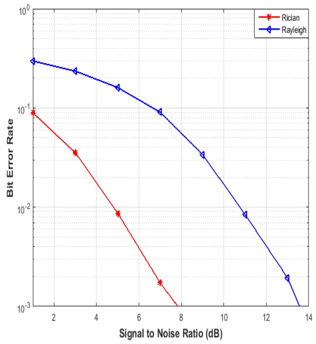

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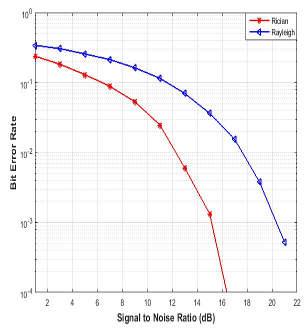
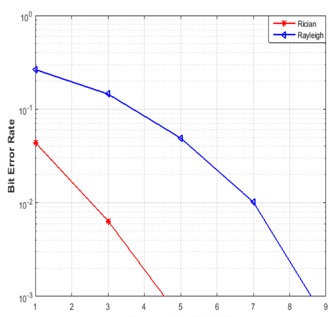


(d)

Figure 4. (a-d) SNR vs. BER Comparison for WiMAX based on BCH encoding over diverse fading channels (a) BPSK, (b) QPSK, (c) 16-PSK, (d) 64-PSK.



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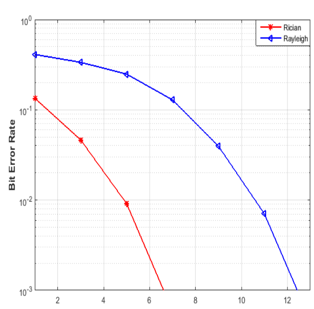

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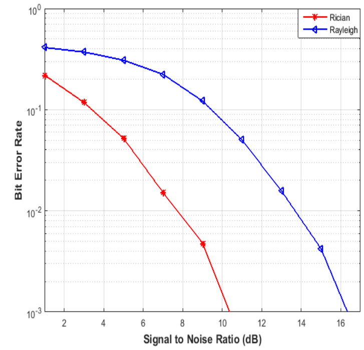

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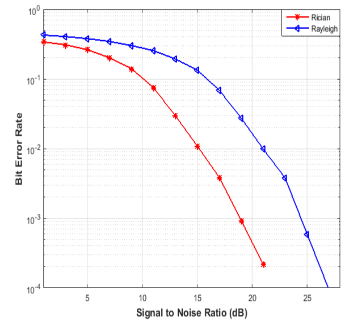
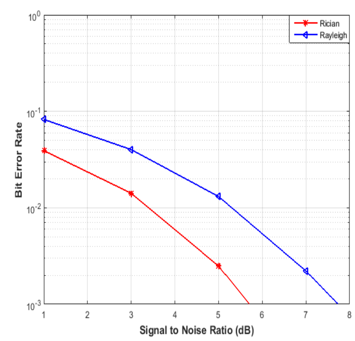


(d)

Figure 5. (a-d). SNR vs. BER comparison for WiMAX based on convolutional encoding over diverse fading channels (a) BPSK, (b) QPSK, (c) 16-PSK, (d) 64-PSK.



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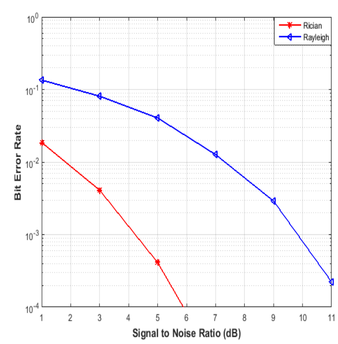

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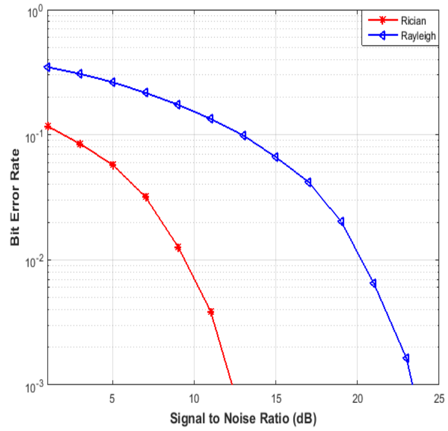

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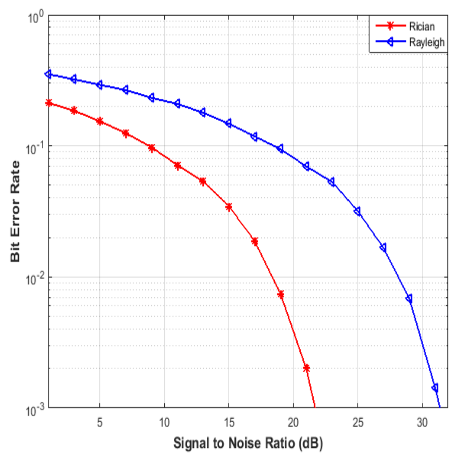
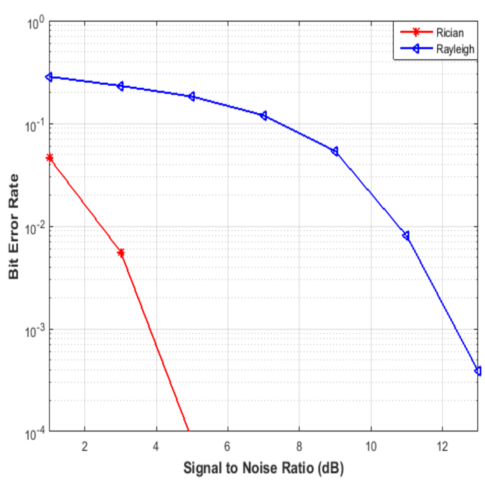


(d)

Figure 6 (a-d). SNR vs. BER comparison for WiMAX based on LDPC encoding over diverse fading channels (a) BPSK, (b) QPSK, (c) 16-PSK, (d) 64-PSK.



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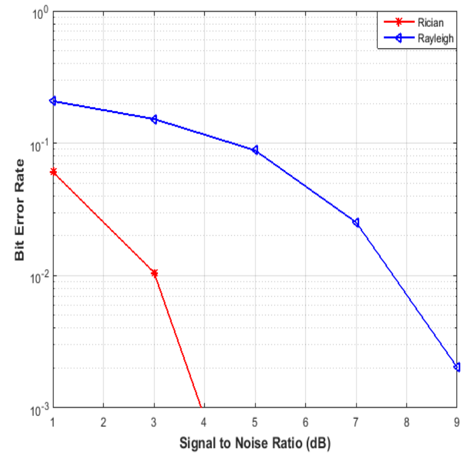

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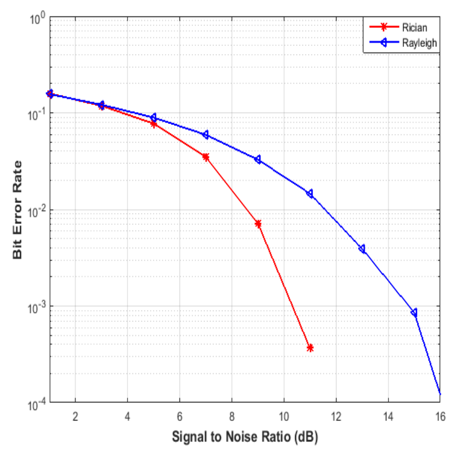

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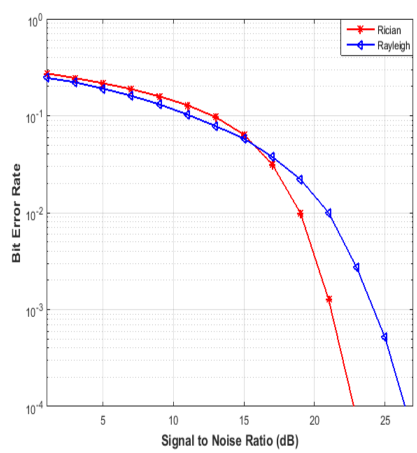

(d)

Figure 7 (a-d). SNR vs. BER comparison for WiMAX based on RS encoding over diverse fading channels (a) BPSK, (b) QPSK, (c) 16-PSK, (d) 64-PSK.

Table 1. Summary of results

Modulation	SNR(dB) required to achieve a BER of 10^{-3}							
	Rician Channel				Rayleigh Channel			
	BCH	LDPC	RS	CC	BCH	LDPC	RS	CC
BPSK	5.7	5.7	3.8	4.5	9.5	7.6	12.4	8.5
QPSK	5.8	4.2	3.95	6.5	8.2	9.9	9	12.3
16-PSK	7.8	12	10.3	10.4	13.5	23.5	14.9	16.3
64-PSK	15	21.5	21.7	18.4	20.3	31.2	24	24

In Figure 6(a), the BER of WiMAX system using BPSK and LDPC codes is shown for both channels. It shows that to have an error rate of 10^{-3}, SNR required for Rician channel is about 5.7 dB and SNR required for Rayleigh channel is 7.6 dB. There is an SNR improvement of about 1.9 dB. If we see Figure 6(b), which shows BER of WiMAX system using QPSK and LDPC codes in the mentioned fading channels, we can see that for a BER of 10^{-3} Rician channel requires an SNR of 4.2 dB and Rayleigh channel requires an SNR of 9.9 dB. For this case, there is an SNR improvement of about 5.7 dB in Rician channel. We have a WiMAX system using 16-PSK and LDPC codes in Rayleigh and Rician channels shown in Figure 6(c). For a BER of 10^{-3}, Rician channel requires an SNR value of 12 dB and Rayleigh channel requires an SNR of 23.5 dB. The improvement in SNR is about 11.5 dB in Rician channel compared to another channel. BER versus SNR graph for a WiMAX system using 64-PSK and LDPC codes has been shown in Figure 6(d). For a BER of 10^{-3}, Rician channel must have an SNR of 21.5 dB and Rayleigh channel must have an SNR of 31.2 dB. From this we can see, there is an SNR progress of about 9.7 dB in case of Rician channel over Rayleigh channel. In Figure 7(a), we have the BER of WiMAX system using BPSK modulation and RS codes which show that for a BER of 10^{-3}, SNR required for Rician channel is about 3.8 dB and SNR required for Rayleigh channel is 12.4 dB. There is an SNR improvement of about 8.6 dB. We have BER versus SNR graph of WiMAX system using QPSK modulation and RS codes in Figure 7(b). In this figure, we can see that for a BER of 10^{-3}, Rician channel necessities an SNR of 3.95 dB and Rayleigh channel necessities an SNR of 9 dB, that is, there is an SNR improvement of about 5.05 dB in the case of Rician channel. A glance at Figure 7(c), shows a WiMAX system using 16-PSK modulation and RS codes in Rayleigh and Rician channels. To get a bit error rate of 10^{-3}, Rician channel must have an SNR value of 10.3 dB and at the same time, Rayleigh channel requires an SNR of 14.9 dB for the same showing an improvement in SNR of about 4.6 dB in Rician channel over the Rayleigh channel. If we have a look at the next figure, we have the BER versus SNR graph for a WiMAX system using 64-PSK and RS codes. To get a BER of 10^{-3}, Rician channel requires an SNR of 21.7 dB and Rayleigh channel requires an SNR of 24 dB. SNR has improved of by 2.3 dB in the case of Rician channel over another fading channel as shown in Figure 7(d). The table which summarizes the results is given in Table 1.

4. Conclusion

With these simulation results, we can say that in any case the response of Rician channel is better than that of Rayleigh channel, no matter which forward error correction code is used or what modulation order of PSK is used. In the case of BCH code based WiMAX system, we see an improvement of 2.8 dB to about 5.7 dB in various PSK modulation orders where as in the case of convolutional code based WiMAX system we have an improvement of SNR ranging from 4 dB to about 6 dB. If we analyze a WiMAX system using LDPC codes, the results show a wide variation in SNR improvement for various PSK modulations ranging between 1.9 dB to11.5 dB. Atlast, the system based on 802.16e using RS codes and two channels show a better response when FEC code used is RS code. The reduction in the value of SNR for a particular BER value ranges in between 2.3 dB and 8.6 dB for various modulation orders. All the improvements are in the Rician channel with respect to Rayleigh channel. In any of the cases discussed above we can conclude that bit error rate of the system decreases exponentially for a lower value of the signal to noise ratio in Rician channel compared to that of Rayleigh channel. We, therefore, prefer Rician channel, where there is atleast one line of sight component in the analysis of systems rather than Rayleigh channel where there is no line of sight component. Hence, in Rician fading channel, the BER performance of a WiMAX system is much better than Rayleigh fading channel.

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