PERFORMANCE OF CODED 16-QAM OFDM MODULATION WITH EQUALIZER OVER AN AERONAUTICAL CHANNEL

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ABSTRACT

The main objectives of iNET (Integrated Network Enhanced Telemetry) are increased data rate and improved spectral efficiency [1]. In this paper we propose that transmission scheme for the physical layer is coded 16-QAM OFDM (Quadrature Amplitude Modulation-Orthogonal Frequency Division Multiplexing) which enables high data rate and spectrum efficiency. However in high mobility scenarios, where the channel is time-varying the receiver design is more challenging. Therefore in this paper pilot-assisted channel estimation is used at the receiver, with convolutional coding and error correction to enhance the performance; while the effect of inter symbol interference (ISI) is mitigated by cyclic prefix.

The focus of this paper is to evaluate the performance of OFDM with 16-QAM over an aeronautical channel. The 16-QAM with OFDM enables 4 bits/symbol and provides a higher data rate than QPSK hence it is chosen in this paper. The implementation of OFDM is done using Inverse Fast Fourier Transform (IFFT) and the Fast Fourier Transform (FFT). In this paper we simulate how the performance of Coded 16-QAM OFDM is enhanced using equalization to compensate for inter symbol interference, convolutional coding is used for error correction, puncturing for improving data rate and the insertion of cyclic prefix (CP) to avoid inter carrier interference.

KEY WORDS

OFDM, CP, CODING, EQUALIZATION, 16-QAM.

1. INTRODUCTION

The Integrated Network Enhanced Telemetry (iNET) study was proposed by the Director of the Central Test and Evaluation Investment Program (CTEIP) with the aim of improving networking and telemetry technologies. The proposed system aims to increase and enhance data transfer between aircrafts and base stations and air –to –air communication [1].

The demand for high speed wireless systems dictates the use of bandwidth efficient modulation schemes. This paper discusses the performance of 16-QAM OFDM over an aeronautical channel. It analyzes the performance of OFDM over an aeronautical channel and shows how the addition of a good equalizer, cyclic prefix and coding scheme [2] can greatly improve its performance. 16-QAM OFDM with convolutional encoding is shown here to be suitable for such applications. The performance of this scheme over a multipath channel is improved by using pilot-assisted channel estimation and equalization, cyclic prefix and convolutional coding. Comparisons between the coded and un-coded system is simulated and the coding gain is calculated.

This paper addresses the radio link aspect of the iNET program. The aeronautical channel, which is time-varying, is utilized primarily for communication between aircrafts and ground stations and for air-to-air communication. This channel in practice is far from perfect, it is characterized by multipath, doppler spread, doppler shift and noise; which results in channel distortion at the receiver. The iNET program seeks to address the critical issues related to the optimization of the limited bandwidth and performance enhancement of the aeronautical channel under adverse channel conditions. The program proposes the use of OFDM in the physical layer of the Telemetry Network System because of its high spectral efficiency and its resilience to poor channel conditions. The organization of the paper is as follows: In section 2 the system model for the proposed Coded 16-QAM OFDM system is given. The proposed pilot-assisted channel estimation approach for 16-QAM OFDM based on comb-type pilot insertion method is introduced in section 3. In section 4 the system architecture is discussed and in section 5, the bit error rate (BER) performance of the proposed technique is evaluated through (MATLAB) computer simulation results.

2. SYSTEM MODEL

The OFDM system transmission scheme is shown in figure 1 below.

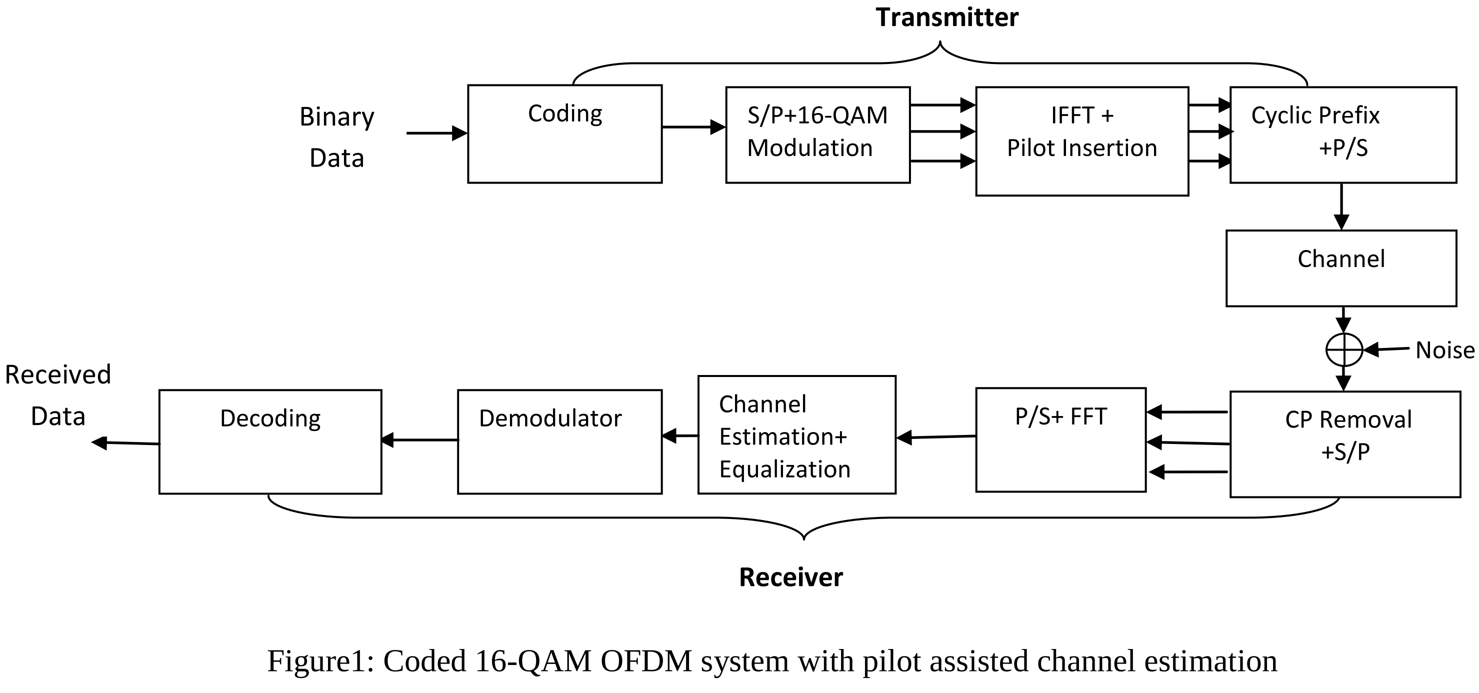


Figure1: Coded 16-QAM OFDM system with pilot assisted channel estimation

2.1. TRANSMITTER OVERVIEW

Error correction codes allow for reliable communication of an information sequence over a multipath channel with additive noise, which introduces bit errors or distorts the signal. Convolutional coding is one type of error-correcting code where the coded data is obtained by using a linear finite-state register [3]. In general the shift register consists of k-bits (stages) and n linear algebraic function generators. The binary input data to the encoder is shifted into and along the shift register k bits at a time [3]. The number of output bits for each k-bit input sequence is n bits. Consequently, the code rate is defined as R=k/n [4]. In this work the input data, which is a serial binary digital stream, is encoded by rate ½ convolutional coding for error correction. The encoded data will then be modulated using one of the digital modulation scheme.

The modulation scheme in an OFDM system can be selected based on the requirements of power or spectrum efficiency. The type of modulation used in this work is 16-QAM since it allows higher spectral efficiency than BPSK or QPSK. 16-QAM is a digital modulation technique where both amplitude and phase are changed [3], and we achieve an increased data rate by increasing the number of bits per symbol to 4 bits/symbol.

OFDM is multicarrier modulation which uses a large number of narrow band sub-carriers to transport data instead of using a single wide-band carrier. OFDM is spectrally efficient and with coding, it is robust against frequency-selective fading [2]. The QAM modulated signal is placed on N orthogonal subcarriers; N is chosen to be 64 (64-point FFT) for this work following the IEEE 802.11a standard. The implementation of OFDM modulation/demodulation is done using the FFT and IFFT.

The insertion of a cyclic prefix (CP) is one of the critical steps that have to be implemented at the OFDM transmitter to reduce inter-carrier interference (ICI) caused by overlapping between symbols of an OFDM signal [3]. A CP of length N/8 is applied as a guard band between the OFDM signals to remove ICI. CP is done by pre appending the last part of the OFDM frame to the beginning of the OFDM frame [3]. The necessary length of the CP depends on L, the order of the FIR channel. Since the channel order may vary in practical systems, the OFDM transmitter must be aware of the maximum channel delay spread. The major disadvantage of inserting a longer-than-necessary CP is the waste of channel bandwidth. To understand this drawback, in OFDM transmission the CP makes possible the successful transmission of N data symbols with time duration of (N+L) T; where N is the size of FFT, L is the length of CP and T is the duration of one data symbol. The L cyclic prefix symbols are introduced by OFDM as redundancy to remove ISI in the original frequency selective channel because (N+L) symbol periods are now being used to transmit the N information data, the effective data rate of the OFDM equals

$$\frac{N}{N+L}\frac{1}{T} \tag{1}$$

As we can see if L is too large the effective data rate is reduced, so the transmission of an unnecessarily long cyclic prefix wastes channel bandwidth. For this reason, OFDM transmitters require accurate knowledge about the channel delay spread to achieve good spectral efficiency [5].

Data sent through a communication channel is affected by several factors such as noise, multipath, interference and fading, which causes distortion at the output. In this research, we minimize noise and multipath effects by applying mechanisms such as coding, OFDM with cyclic prefix and equalization. The experimental results show how the performance of OFDM, which is degraded by additive white Gaussian noise (AWGN) and multipath channel, can be improved.

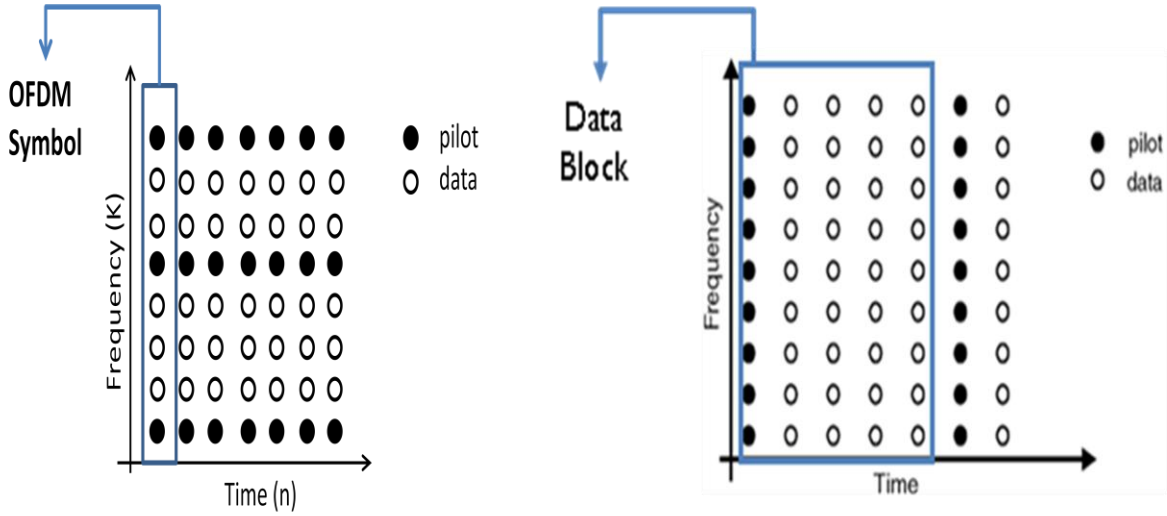
3. RECEIVER OVERVIEW

At the receiver side, the convolved signal has been affected by noise and multipath causing inter-symbol interference (ISI), and so we use an equalizer to compensate for inter symbol interference. Subcarriers are removed using the FFT and an estimate of the channel response is produced. The signal is then demodulated and decoded using the very efficient Viterbi decoding.

3.1. CHANNEL ESTIMATION AND EQUALIZATION

In OFDM systems, the transmitter modulates the message bit sequence using PSK and/or QAM then performs IFFT on the symbols and sends them out through a (wireless) channel. The received signal is usually distorted by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated for in the receiver. Each subcarrier can be regarded as an independent channel, provided ICI is suppressed thus maintaining the orthogonality among subcarriers. The orthogonality allows each subcarrier component of the received signal to be independently expressed as the product of the transmitted signal and channel frequency response at the subcarrier. Thus, the transmitted signal can be recovered by estimating the channel at each subcarrier. In general, the channel can be estimated using symbols known to both transmitter and receiver. Various interpolation techniques are employed to estimate the channel response between subcarriers. Channel estimators are introduced at the receiver to generate a moderate estimate of the channel impulse response. With this channel estimate, an equalizer can be developed and applied at the receiver for minimizing inter-symbol interference. In OFDM the channels being estimated for each subcarrier are narrowband, so the equalizer is simply the inverse of the channel. The channel estimate might not be an exact equivalent to the actual channel; however, it possesses enough of the behaviour of the actual channel to reduce errors in the signal demodulation. The closer the estimated channel is to the actual channel, the more accurate is the equalizer and hence the lower the error in the received data.

Based on the principle of OFDM transmission it is easy to assign the pilots both in the time-domain and/or frequency-domain. There are two major types of pilot arrangements as shown in figure 2, which are comb-type and block-type pilot insertion methods. In this paper, we consider comb-type pilot insertion method since it provides good channel estimation for the fast time-varying channels. In this scheme, the pilots are inserted uniformly at selected sub carriers and transmitted at every time instant as shown in figure 2. In the standards, certain sub-carriers are reserved for pilot symbols in the form of N_p pilot signals uniformly inserted in input data X(k).



(a) Comb-Type

(b) Block Type

Figure 2: Comb-Type and Block-Type Pilot Insertion Scheme

An OFDM symbol spans all sub carriers in the available bandwidth as shown in figure 2. Using comb-type estimation the pilot symbols are inserted uniformly within each OFDM symbol and transmitted on all symbols**.** Since pilots are inserted in every symbol, the channel is estimated at every instant making this scheme ideal for fast time-varying channels as the pilots will be able to continuously track the channel variation [6]. The receiver has information on the location and values of the pilot symbols and of course, the received signal. OFDM symbol transmission is shown in figure 3 below:

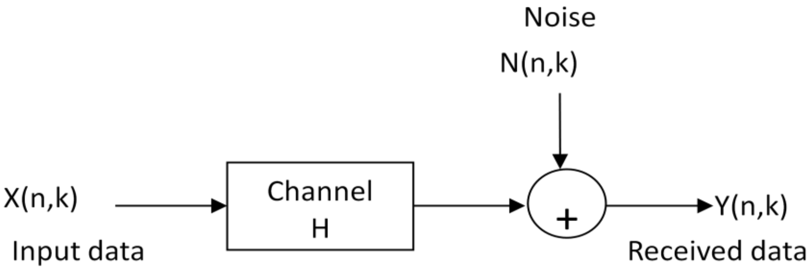


Figure 3: Block Diagram showing signal transmission

The received data symbols can then be expressed in the frequency domain by

$$Y_{n,k} = H_{n,k}X_{n,k} + N_{n,k} \tag{2}$$

The channel impulse response at the pilots can be estimated by

$$H_{n,k}^{p} = \frac{Y_{n,k}^{p}}{X_{n.k}^{p}} \tag{3}$$

where $H_{n,k}^{p}$ is the channel estimate of the pilot at the nth time on the kth sub-carrier.
$Y_{n,k}^{p}$ is the received pilot at the nth time on the kth sub-carrier.

$X_{n.k}^{p}$ is the transmitted pilot at the nth time on the kth sub-carrier.

The channel conditions at the data sub carriers can be estimated using the pilot sub carriers by dividing the received pilot tones by the transmitted pilot tones. More details on equations (2) and (3) could be found in [6].

Frequency domain interpolation is done by using the FFT to find the frequency response of the estimated channel. Once the frequency response of the estimated channel is determined, an equalizer is developed by simply taking the inverse of the estimated channel.

4.SYSTEM ARCHITECTURE

In current and future mobile communication systems, data communication at higher data rate is essential. When the data is transmitted at higher bit rates over aeronautical channels, inter symbol interference (ISI) occurs [5]. ISI is caused by multipath and it is the spreading and smearing of symbol such that one symbol affects the next ones in such a way that the received signal has a higher probability of being interpreted incorrectly.

Input data streams that are coded at the code rate ½, convolutional code are frequently used to correct errors in noisy channels. They have good correcting capabilities and perform well even on very bad channels. Convolutional codes are commonly specified by three parameters (n,k,m) where n=number of output bits, k= number of input bits and m=number of memory registers and code rate =k/n is a measure of efficiency of the code. The constraint length L=k(m-1) represents the number of bits in the encoder memory that affects the generation of the n output bits.

Puncturing can be applied for code rates 1/2 ,1/3 ,1/4 and 1/7 to produce punctured codes which give us higher code rates other than 1/n for example, by using two rate ½ codes together and just not transmitting some of the output bits we can convert this rate ½ implementation into 2/3 code rate [3]. Rates can be changed dynamically depending on the channel conditions which is an advantage**.**

After modulation, the modulated output is divided orthogonally to N carriers; N is chosen to be 64 (with a 64-point FFT) for this analysis. IFFT is used to convert the modulated data in the frequency domain to the time domain and pilot tones are inserted for equalization purposes. An OFDM signal offers an advantage in a channel that has a highly frequency-selective response. OFDM system is also more resilient in multipath environment. It can efficiently overcome interference and frequency selective fading caused by multipath. The effect of ISI is suppressed by virtue of a longer symbol period (by addition of a cyclic prefix) and equalization.

At the receiver, the inverse operations are performed (see figure 1) and the data is finally decoded. There are two types of decoding algorithms which can be used with convolutional encoding; they are Viterbi decoding and sequential decoding. In this paper, hard decision decoding based on Viterbi is used. It compares the received sequence to all permissible sequence and picks the one with the smallest Hamming distance.

5. EXPERIMENTAL RESULTS

Monte Carlo simulations using Matlab are carried out to evaluate the performance of the proposed pilot-assisted equalizer for OFDM symbols with coding and cyclic prefix. For the simulations, the 16-QAM OFDM is transmitted and the evaluation is done by measuring the symbol error rate (SER) over Eb/No (dB).

In this section two simulation results are presented in which the performance of the proposed 16-QAM OFDM is evaluated over a range of Eb/No ranging from 0 dB to 27 dB. In this simulation 64-bit data is randomly generated and encoded using rate ½ convolutional coding .The multipath channel used is [1, 0, 0.5, 0, 0.25] and the data is modulated over an FFT size of 64. The cyclic prefix, which is used as a guard band is of length 8, which is one eighth of the FFT size. A pilot spacing of 8 is used and there were 500 iterations for each evaluation.

The average symbol error rate (SER) for four scenarios, are shown in figure 4. The scenarios compared are uncoded with no equalizer, with equalization alone, with equalization and coding and the theoretical curve with no multipath. As we can see from the figure 4 at higher Eb/No values the SER ratio of equalization with coding is lower than that of equalization with no coding. Moreover, we note that the coding gain at a SER of 10^{-4} from the (equalized but uncoded to the equalized and coded output) is approximately 4 dB, which is a significant improvement. Thus there is an improvement in the SER from adding an equalizer and then including coding.

The frequency response of the actual channel and the estimated channel, at 20 dB Eb/N_0 is shown in figure 5a. We note the small error in the frequency response of the estimated channel when compared to that of the actual channel. The frequency response of the actual channel and the estimated channel at 27dB Eb/No is shown in Figure 5b. We note that the frequency response of the estimated channel is very close to that of the actual channel.

The mean square error between the actual and the estimated channel is shown in Figure 6. We observe that this is error is lower at higher values of Eb/No with a value of 4e-2 at Eb/No of 27 dB.

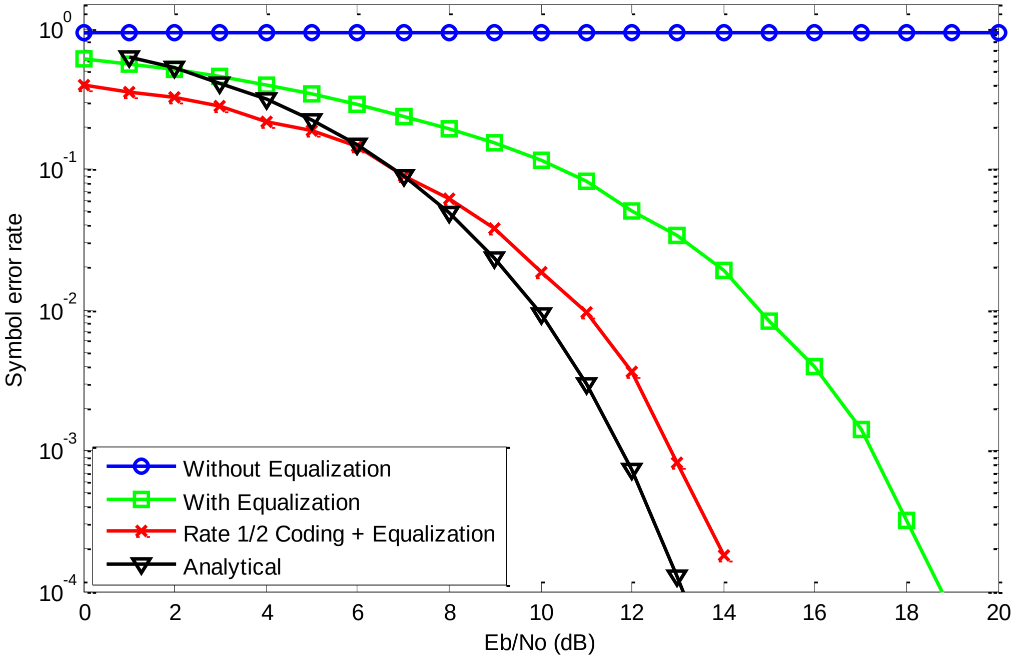
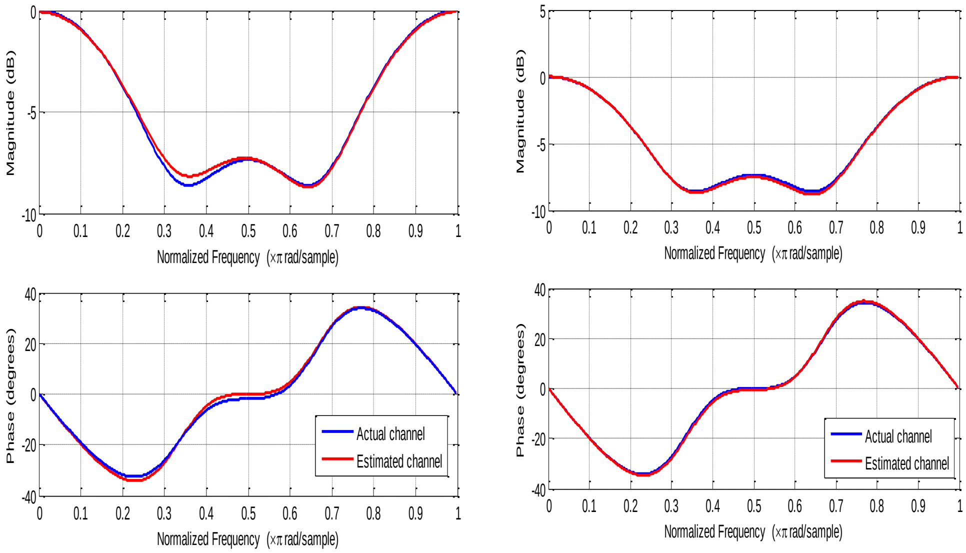


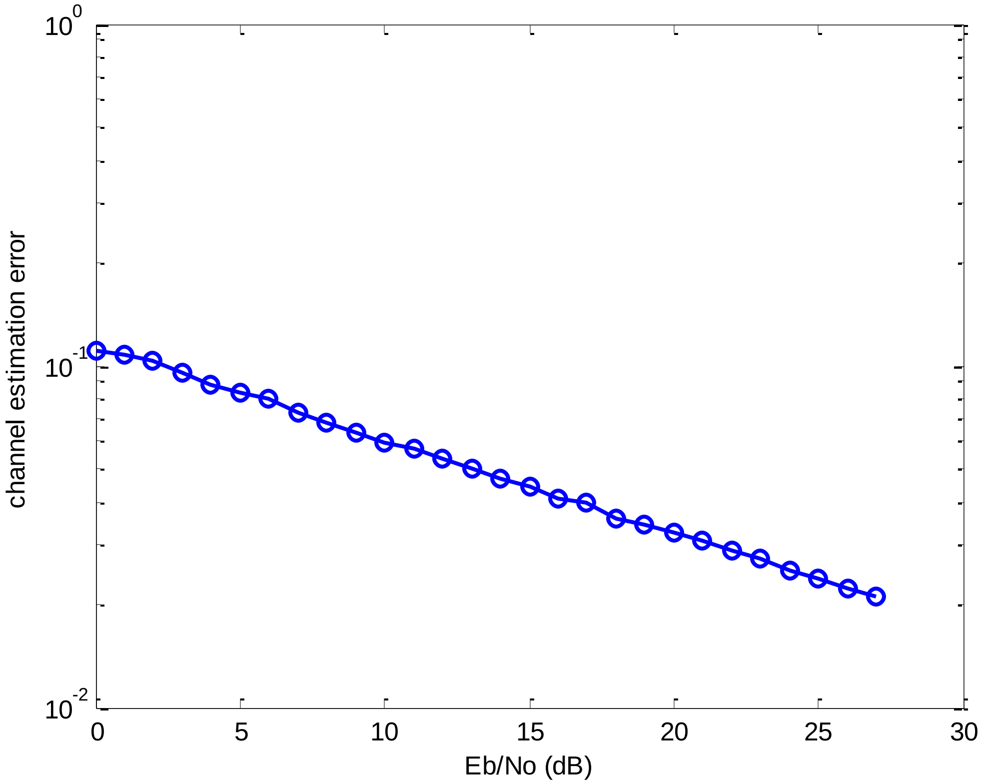
Figure 4: Comparison of SER of different scenarios for 16-QAM OFDM



(a) Eb/No =20dB

(b) Eb/No = 27dB

Figure 5: Comparison of the frequency response of the estimated and actual channels



. Figure 6: Mean square Channel estimation error between the actual and estimated channel.

6. CONCLUSION

In this paper pilot-assisted equalization has been presented for a spectrally efficient 16-QAM OFDM system. Moreover the improvement due to the addition of an equalizer with coding has been shown to be significant. To minimize the symbol error rate for the 16-QAM OFDM system, three methods are applied which are equalization, convolutional coding and the addition of cyclic prefix. From the results of figure 4, we show that coding with equalization provides better bit error performance than with equalization only. By applying these methods to the 16-QAM OFDM data transmitted over the aeronautical channel, the reduction of bit error rates to the desired level is demonstrated. The incorporation of equalization and coding with OFDM for the channel selected not only enables operation on this difficult channel, it brings the performance to within 1 dB of the theoretically performance.

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Bibliography

[1] "iNET Network Telemetry System Architecture," May 2004.

[2] Iickho Song, Hong Gil Kim, Yun Hee Kim, "Performance Analysis of a Coded OFDM System in," *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, SEPTEMBER 1999.

[3] John G Proakis, *Digital communications*, 4th ed. New York: McGraw Hill, 2001.

[4] Theodore S.Rappaport, *Wireless Communications principles and practice*. Upper Saddle River, United States of America: Prentice Hall PTR, 2002.

[5] B.P.Lathi Ding, *Modern Digital and Analog Communication Systems*, 4th ed. New York, USA: Oxford University Press, 2009.

[6] Le Ruyet D., Panazio C., Ozbek B., "Pilot Symbol Iterative Channel Estimation for OFDM-Based Systems," in *European Signal Processing Conference*, Turkey, 2005.