

## Color Image Transmission: Error Analysis of a Concatenated FEC Scheme Based OFDM System

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**Abstract:** Orthogonal Frequency Division Multiplexing (OFDM) systems have become popular recently for providing high data rate multimedia services over severe multipath channels which can offer high speed voice, video and data service up to the customer end. In this study, the performance of a concatenated interleaved FEC (Forward Error Correction) scheme based OFDM communication system on digital image transmission under different combinations of digital modulation (BPSK, QPSK, 4-QAM and 16-QAM) over both Additive White Gaussian Noise (AWGN) and fading (Rician and Rayleigh) channels have been discussed. The simulation study is made with the processing of a color digital image under AWGN and different fading channels. It is observed from the simulation study that the modulation technique used is robust in discrimination of the transmitted digital image in both AWGN and fading environments.

**Key words:** OFDM, concatenated code, additive white gaussian noise, fading channel, color image transmission, bit error rate analysis

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### INTRODUCTION

Wireless and mobile communications has become one of the fastest growing areas in the modern life and it has an enormous impact on almost every aspect of the daily life (Tran *et al.*, 2008). The demand of wireless communication is growing exponentially and next generation of wireless broadband multimedia communication systems will integrate various function and application in same system which supports large data rates with sufficient robustness to radio channel impairments, requires careful choosing of modulation technique. The suitable choice is Orthogonal Frequency Division Multiplexing (OFDM) which is special case of multi-carrier communication system where single data stream is transmitted over number of lower sub-carrier (Moose, 1994; Dwivedi and Singh, 2008).

OFDM is a bandwidth efficient signalling scheme where the orthogonality among the subcarriers should be maintained to a high degree of precision. Since, the spectra of the sub-carriers are overlapping an accurate frequency synchronization technique is needed. However, due to oscillator inaccuracies and non-ideal receiver synchronization, the orthogonality of subcarriers is compromised resulting in Intercarrier Interference (ICI) which can degrade the performance of OFDM systems significantly (Stantchev and Fettweis, 2000). The commonly used method in determining the quality of wireless link is BER, the BER conveys the Channel State Information (CSI) effectively (Smit *et al.*, 2004).

The present study is intended to investigate, the performance of a digital image transmission for OFDM communication system with the deployment of different modulation techniques in various noisy environments. In designing a wireless communication system, generally the effect of noise in the mobile channel and the effects of multipath fading during propagation of radio wave through free space are crucial issue (Stallings, 2004).

This study deals with the analysis of the digital image transmission through a typical transmission channel. Usually image transmission has to pay enormous cost of bandwidth and need to have lossless reproduction. Hence, we are going to evaluate the performance of a communication channel under certain environment when dealing with digital images. The simulation deals with non-compressed digital image transmission by a model of the digital transmission channel baseband. The whole simulation is aimed at the research and education area of the digital signal transmission in baseband and quantification and evaluation of the distortion that may have influence on the transmitted digital signal according to the time and frequency domain. The main goal is to evaluate the performance different modulation scheme for digital image transmission over both AWGN and fading (Rician and Rayleigh) channels through OFDM communication system and assess the performance of concatenated interleaved transmission. In fading channel, the errors in mobile radio systems tend to arrive in blocks and a burst of errors is reduced in block interleaver which essentially

mixes up the RS-CC encoded bit stream in a set of symbols before transmission and reorders them in reception.

## MATERIALS AND METHODS

This structure corresponds to the physical layer of the IEEE 802.16 Wireless MAN-OFDM air interface. In this setup, the input binary data stream obtained from a segment of real image signal is ensured against errors with Forward Error Correction codes (FECs) and interleaved and the complementary operations are applied in the reverse order at channel decoding in the receiver end. The complete channel encoding setup is shown in Fig. 1.

**RS encoder:** The channel encoder has the task of reducing the bit error rate, to ensure secure communications. Moreover, concatenation has proved to yield better results wherein it provides a solid introduction to foundation mathematical concept of galois field algebra and its application. Here, the encoding process consists of a concatenation of an outer Reed-Solomon (RS) code and an inner Convolution Code (CC) (Mursanto, 2006) as a FEC (Forward Error Correction) scheme. As specified in the standard, the reed-solomon encoding is derived from a systematic RS ( $n = 255, k = 239, t = 8$ ) code using a Galois Field specified as  $GF(2^8)$ . The primitive and generator polynomials used for the systematic code are expressed as follows:

**Primitive polynomial:**

$$P(x) = x^8 + x^4 + x^3 + x^2 + 1$$

**Generator polynomial:**

$$G(x) = (x + \beta^0)(x + \beta^1)(x + \beta^2) \dots (x + \beta^{2t-1})$$

The primitive polynomial is the one used to construct the symbol field and it can also be named as field generator polynomial (Raut and Kulat, 2008). The code generator polynomial is used to calculate parity symbols and has the form specified as before where  $\beta$  is the primitive element of the galois field over which the input message is defined.

A complex convolution encoder with constraint length 7 given to the standard of IEEE 802.16 is used to correct the random errors in the data transmission.

**Convolutional encoder:** The generator polynomials for this encoder are  $g0 = 171$  oct and  $g1 = 133$  oct. The

encoder can easily be implemented in hardware shift registers. The first step is to represent the input bit string as a polynomial. Any sequence of 0's and 1's can be represented as a binary number or a polynomial (Taylor, 2001). The convolutional encoder for OFDM ( $g0 = 171$  oct and  $g1 = 133$  oct) can be represented as follows:

$$g0 = 1 + D + D^2 + D^3 + D^6 \text{ and } g1 = 1 + D^2 + D^3 + D^5 + D^6$$

The convolutional encoder basically multiplies the generator polynomials by the input bit string as follows:

$$\begin{aligned} A(x) &= g0(x) * I(x) = abc\dots g \\ B(x) &= g1(x) * I(x) = PQR\dots V \end{aligned}$$

Interleaving the two outputs from the convolutional encoder yields  $E(x) = aPbQcR\dots gV$  which can also be written as:

$$\begin{aligned} E(x) &= (a0b0c0\dots g0) + (OPOQOR\dots OV) \\ &= A(x2) + x * B(x2) \end{aligned}$$

Therefore,

$$E(x) = A(x2) + x * B(x2)$$

and

$$A(x2) = g0(x2) * I(x2)$$

and

$$B(x2) = g1(x2) * I(x2)$$

with the following:

$$\begin{aligned} E(x) &= g0(x2) * I(x2) + x * g1(x2) * I(x2) \\ &= I(x2) * (g0(x2) + x * g1(x2)) \\ &= I(x2) * G(x) \end{aligned}$$

Where:

$$G(x) = g0(x2) + x * g1(x2)$$

$$G(x) = 1 + x + x^2 + x^4 + x^5 + x^6 + x^7 + x^{11} + x^{12} + x^{13}$$

The convolutionally, encoded bits are interleaved further prior to convert into each of the either four complex modulation symbols in BPSK, QPSK, 4-QAM, 16-QAM modulation and fed to an OFDM modulator for transmission.

**OFDM modulator:** In OFDM modulator, the digitally modulated symbols are transmitted in parallel on

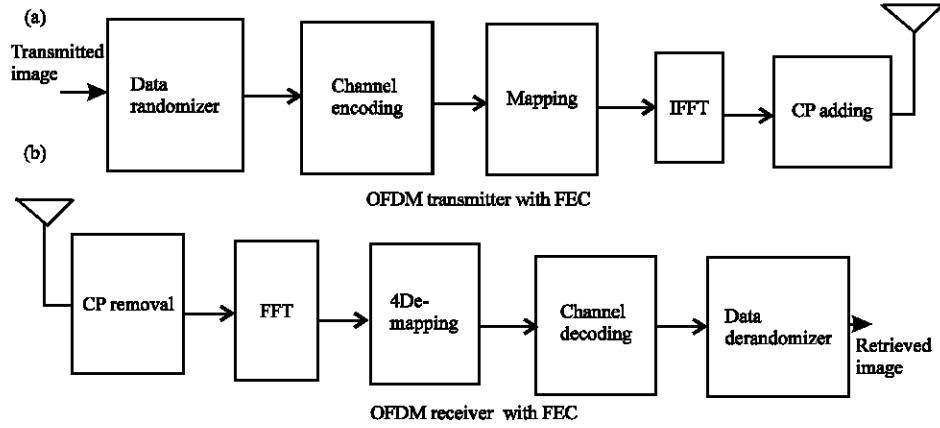


Fig. 1: Simulation model developed for OFDM

subcarriers through implementation as an Inverse Fast Fourier Transform (IFFT) on a block of information symbols. The available transmission bandwidth is divided into  $n$ th subchannels in orthogonal nature to obtain high spectral efficiency with  $t$ -time domain samples at the output of IFFT is given by:

$$x_t = \sum_{n=0}^{N-1} x_n \exp\left\{j2\pi f_n \frac{t}{N}\right\} \quad 0 \leq t \leq N-1$$

where,  $N$  is the number of subcarriers and the subcarriers number are defined by 256.  $x_n$  is the data symbol on the  $n$ th subcarrier. As a result an OFDM symbol is generated. For length  $N$  input sequence  $x$ , the DFT is a length  $N$  vector,  $X$ . FFT and IFFT implement the relationships in these given equation (Duhamel and Vetterli, 1990):

$$x(k) = \sum_{n=-1}^N x(n) e^{-j2\pi(k-1)(n-1/N)} \quad 1 \leq k \leq N$$

and

$$x(k) = \frac{1}{N} \sum_{K=1}^N x(n) e^{-j2\pi(k-1)(n-1/N)} \quad 1 \leq n \leq N$$

To mitigate the effects of Inter-Symbol Interference (ISI) caused by channel time spread each block of IFFT coefficients is typically presented by a cyclic prefix.

At the receiving side, a reverse process (including deinterleaving and decoding) is executed to obtain the original data bits.

As the deinterleaving process only changes the order of received data, the error probability is intact. When passing through the CC-decoder and the RS-decoder, some errors may be corrected which results in lower error rates (Xiao, 2007).

Table 1: Simulation parameters

Parameters	Values (s)
No. of used subcarriers	200
FFT (size)	256
Modulations	BPSK, QPSK, 4-QAM, 16-QAM
RS code	255,239,8
CC code	$\frac{1}{2}$
Cyclic prefix	0.25
Noisy environment	AWGN, Rayleigh, Rician

## RESULTS AND DISCUSSION

The computer simulation has been used to study the performance of the CDMA system. In particular, we would like to make a comparison amid four different modulation techniques based on forward error correction code, i.e., reed-solomon codes, convolutional codes. The simulation evaluated the performance of OFDM for Bit Error Rate (BER) values equal to the rate of error of the transmission is verified. The simulation was initialized with an SNR = 0 dB. For image transmissions, a compressed color image is reconverted into a binary image in color jpg (JPEG) format are used in this simulation. The size of this image is 30×84 pixels. Each pixel is represented by 24 bits that is 8 bits are for each of the three components R, G and B. Each pixel value of the image is multiplexed column wise into serial binary stream and is RS-CC encoded. Table 1 shows the parameters when the simulation is considered. The BER performance of the OFDM system in Additive White gaussian noise channel with respect to the average SNR per bit is plotted in Fig. 2 and retrieval image format at jpg plotted in Fig. 3 where the modulation scheme for each subchannel is BPSK, QPSK, 4-QAM, 16-QAM and  $N = 256$  subchannels are used. Comparing with the results in Fig. 4, the BER performance of OFDM-QPSK and OFDM-4QAM is exactly the same and the received image in QPSK and 4-QAM is retrieved almost the same as the

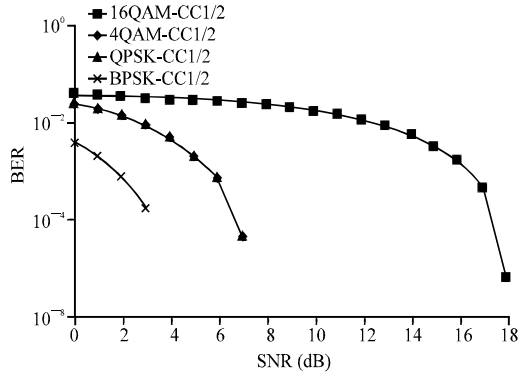


Fig. 2: Bit error rate performance between different modulation techniques of an  $\frac{1}{2}$ -rated RS-CC coded image signal under AWGN channel



Fig. 3: Performance study of a communication system in AWGN channels (SNR = 15 dB) (a) Transmitted image (b) Received image in 2-PSK modulation techniques (c) Received image in QPSK and 4-QAM modulation techniques (d) Received image in 16-QAM modulation techniques

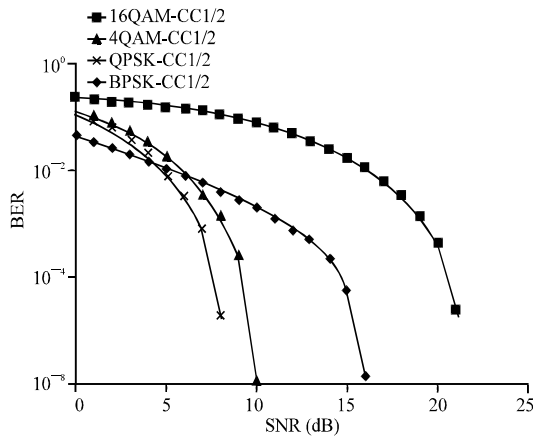


Fig. 4: Bit error rate performance between different modulation techniques of an  $\frac{1}{2}$ -rated RS-CC coded image signal under Rayleigh channel

original image. In Fig. 4, the bit error rate under QPSK and 4-QAM modulation technique over Rayleigh channel with 9 dB SNR value is 0.0000327 which is almost 0 and 16-PSK SNR value of 15 dB (Fig. 5) is 0.0070378 and retrieved the noisy image and it is observed from Fig. 6 that the



Fig. 5: Performance study of a communication system in Rayleigh channels (SNR=15dB) (a) Transmitted image (b) Received image in 2-PSK modulation techniques (c) Received image in QPSK and 4-QAM modulation techniques (d) Received image in 16-QAM modulation techniques

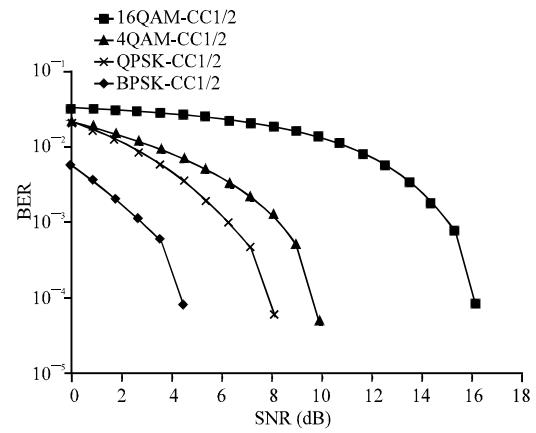


Fig. 6: Bit error rate performance between different modulation techniques of an  $\frac{1}{2}$ -rated RS-CC coded image signal under Rician Channel



Fig. 7: Performance study of a communication system in Rician channels (SNR = 15dB) (a) Transmitted image (b) Received image in 2-PSK modulation techniques (c) Received image in QPSK and 4-QAM modulation techniques (d) Received image in 16-QAM modulation techniques

received image in QPSK and 4-QAM is retrieved almost the same as the original image. As one can observe as the SNR ratio increases, we can use a higher modulation (such as 16 QAM). The use of a higher order modulation allows us to transmit more bits per symbol (ex: 4 bits per symbol for 16 QAM) which results in a higher data rate but this kind of modulation is more susceptible to interference. In Fig. 6, the bit error rate performance with

four different modulation schemes is presented. In the rician multipath fading channel with SNR value of 10 and 14 dB is almost 0 and 16-PSK SNR value of 20 dB is 1.2422e-005 and retrieved the noisier image and it is observed from Fig. 7 that the received image in QPSK and 4-QAM are the same for these two profiles.

### CONCLUSION

In this study, several parameters such as the modulation, coding scheme and the optimal value of the CP were investigated for the case of OFDM system modeled by a AWGN and fading channel model. On the basis of results in the present study, it may be concluded that the performance of the OFDM system in digital color image transmission over AWGN channel is comparatively better as compared to Rayleigh and Rician fading channels and it is also observed from the above discussion, the performance of QPSK and 4-QAM modulation technique is the same and retrieved image signal is the same as the original image. So, this two modulation techniques is efficiently used rather than BPSK because QPSK is double bandwidth efficiency. In absence of any fading effects, the quadrature phase shift keying based modulation/demodulation scheme shows unique performance in proper identification and retrieval of transmitted digital image.

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