Optimal Modulation Techniques for Image Transmission on a Wireless OFDM System

Ameya K. Naik and Nitin S. Nagori

Abstract—**In the last few years, there has been a significant increase in transmission of video and images (facsimile) over wireless channels. This transmission however demands a higher quality in terms of resolution and data rates. In 4G wireless systems, OFDM (Orthogonal Frequency Division Multiplexing) is regarded as potential candidate to satisfy the demanding performance. The performance of any system largely depends on the type of modulation scheme used. In this paper we investigate the performance of an OFDM system for high-resolution image transmission by employing different M-ary modulation schemes. Both AWGN and multipath Rayleigh fading channels are considered. The comparison of the system performances reveals that BPSK modulation scheme is an attractive option under fading channel conditions and also in the presence of noise. Only QAM with M=2 provides a performance comparable to that of BPSK.**

Index Terms—**Modulation, Image Coding, Discrete Cosine Transform, Discrete Fourier Transform, Fading Channels, Gaussian noise.**

I. Introduction

WITH the increasing popularity of mobile communications, research in the area of image transmission over wireless channels has received considerable attention. Also more recently OFDM [1] [2] system has been proposed as a standard for the next-generation mobile communication system. OFDM offers efficient spectral bandwidth as compared to other mobile systems. Moreover the performance of an OFDM system is better than that of the single carrier modulation scheme. These advantages facilitate the transmission of video [3] and images as required in wide range of applications. The performance of any communication system depends on the type of modulation used. When developments of digital wireless communication technologies were started around few decades back, the modulation schemes were limited only to constant envelope modulation schemes [4] (Gaussian filtered minimum shift keying). However recently use of high spectral efficient modulation schemes, such as QPSK [5] (Quaternary Phase Shift Keying) and QAM (Quadrature Amplitude Modulation) has been started since high data rates and capacity is regarded as most important issue to satisfy growing demands of wireless communication services.

In this paper we compare the various M-ary digital modulation schemes as applied to an OFDM system. The pre-processing involves quantization and compression using JPEG standard [6]. The results obtained can act as guidelines to select an appropriate modulation scheme over noisy and fading channels. The paper is organized as follows. Section II describes the system model used for simulation. Section III gives the analytical evaluation of the system. Section IV presents the results obtained for various channels, which is followed by conclusions.

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II. System Description

A. Image Compression Model

The simulation model used for image compression is shown in Fig. 1.

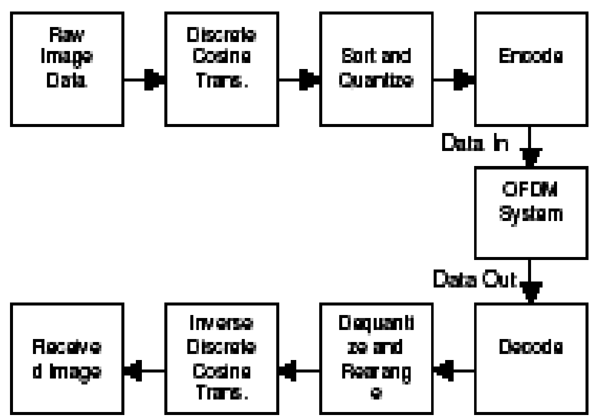

Fig. 1. Block diagram of the system used for compression.

The raw image is first processed to obtain 2-D Discrete Cosine Transform (DCT) [7] coefficients of the image data. The data is sorted and only 4% of the higher coefficients are considered for transmission. These coefficients are then quantized and encoded to be fed to an OFDM system. At the receiver side exactly the reverse operation is performed. The data received from the OFDM system is first decoded. It is then dequantized and rearranged to get back the DCT coefficients. The DCT coefficients which were not transmitted are considered to be zero. An inverse 2-D DCT on the coefficients gives back the original image. The data after encoding is compared with the data before decoding to obtain bit error rate.

B. OFDM System Model

The data obtained after compression is then transmitted using OFDM scheme. The OFDM system [8] is shown in Fig. 2.

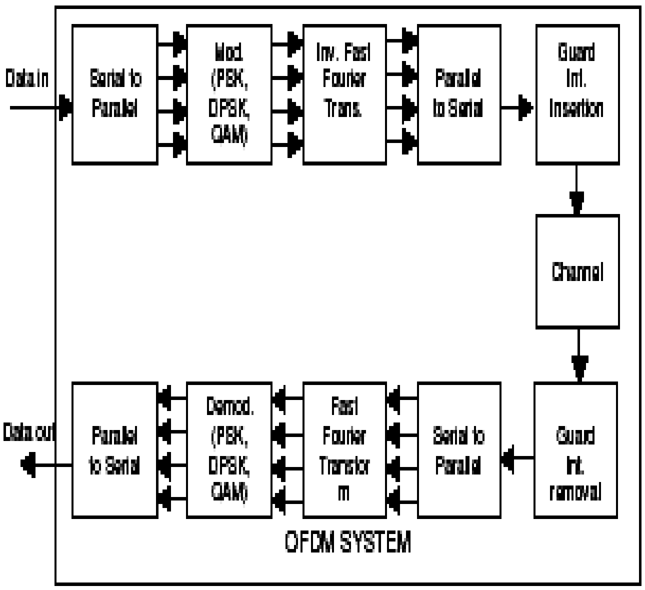

Fig. 2. Data transmission using OFDM System Model

The serial data bit stream is first converted into parallel form to be transmitted over multiple sub-carriers. Each sub-carrier is modulated using various modulation schemes such as PSK (Phase Shift Keying), DPSK (Differential Phase Shift Keying) and QAM (Quadrature Amplitude Modulation). An inverse fast fourier transform operation is then performed. The data is converted into serial form and after adding appropriate guard interval it is transmitted on the channel. At the receiver side the guard interval is removed and converted into parallel form. After performing a FFT (Fast Fourier Transform) the data is then demodulated. The demodulated data is then converted into serial form and sent to de-compressor and image re-constructor

III. PERFORMANCE EVALUATION

The performance of the system discussed in section II will be evaluated in terms of Bit error rate (BER) for various values of E_b/N_0 (Bit energy to noise ratio). Both AWGN (Additive White Gaussian Noise) and multipath Rayleigh Fading Channels are considered. BER for each carrier is the same as that for the single-carrier transmission systems. Hence BER for OFDM is the same as that for single-carrier modulation scheme under both AWGN and flat Rayleigh fading conditions. Even under frequency selective fading conditions, the maximum delay time of delayed paths is considered less than the guard interval. This makes the BER performance [9][10] for uncoded OFDM almost the same as the performance under flat Rayleigh fading conditions (since the guard interval can prevent intersymbol interference to FFT -windowed period). The performance of the system under consideration for various modulation schemes and various channel conditions is depicted in Table I and Table II.

A. AWGN Channel

TABLE I
SYSTEM PERFORMANCE FOR AWGN CHANNEL

Modulation Scheme	Bit Error Rate
Binary Phase shift Keying (M=2)	$P = Q\left(\sqrt{2E_b/N_0}\right)$
Quaternary Phase shift Keying (M=4)	$P = Q\left(\sqrt{2E_b/N_0}\right)\left[1-1/2\,Q\sqrt{2E_b/N_0}\right]$
Differential Phase Shift Keying (M=2)	$1/2\,e^{-E_b/N_0}$
Quadrature Amplitude Modulation (M=2)	$P = 1-\left(1-P_{\sqrt{M}}\right)^2$ where $P_{\sqrt{M}} = 2\left(1-1/\sqrt{2}\right)Q\left(\sqrt{3\varepsilon_{av}/N_0}\right)$
Quadrature Amplitude Modulation (M=4)	$P = 1-\left(1-P_{\sqrt{M}}\right)^2$ where $P_{\sqrt{M}} = Q\left(\sqrt{\varepsilon_{av}/N_0}\right)$

where P= Bit Error probability

Q= $Q(x) = 1/2\,erfc\left(x/\sqrt{2}\right)$

E_b=Bit energy

N_0= Noise spectral density

ε_{av}/N_0 =Average Signal to noise Ratio per symbol

B. Rayleigh Fading Channel

TABLE II
SYSTEM PERFORMANCE FOR RAYLEIGH CHANNEL

Modulation Scheme	Bit Error Rate
Binary Phase shift Keying (M=2)	$1/4\bar{\gamma}_b$
Differential Phase Shift Keying (M=2)	$1/2\bar{\gamma}_b$
M-ary PSK and DPSK	$P_M = \frac{M-1}{(M\log_2 M)\left[\sin^2(\pi/M)\right]\bar{\gamma}_b}\{for\ L=1$

where $\tilde{\gamma}_b$ =Average signal to noise ratio

L= Diversity order.

IV. RESULTS AND DISCUSSION

The image used as a raw data is a high resolution image (fig. 3) (512x512 pixels).

Fig. 3. Original Image used as Raw data.

The image is first converted into binary form to be transmitted using OFDM system. Using JPEG compression scheme only 10400 coefficients along with their indices are transmitted. This gives a compression ratio of approximately 82%. Various modulation schemes are considered for transmission such as PSK, DPSK and QAM. The performance is evaluated in terms of BER (Bit Error Ratio) versus bit energy to noise ratio (E_b/N_0). The performance is also depicted for higher order modulation (M=2 and M=4). Fig. 4 shows the plot of BER versus E_b/N_0 for AWGN channel.

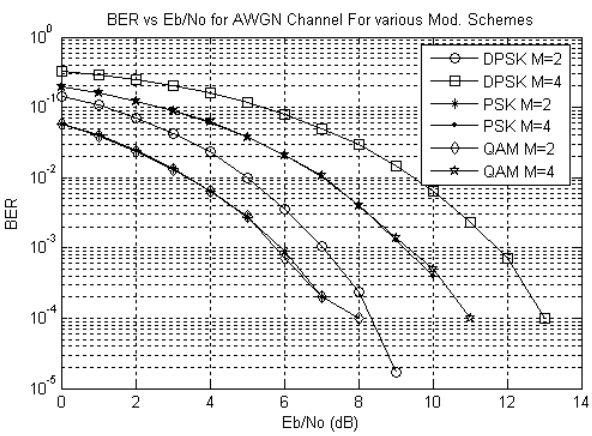

Fig. 4. BER versus E_b/N_0 for AWGN Channel with DPSK, PSK and QAM for M=2 and 4.

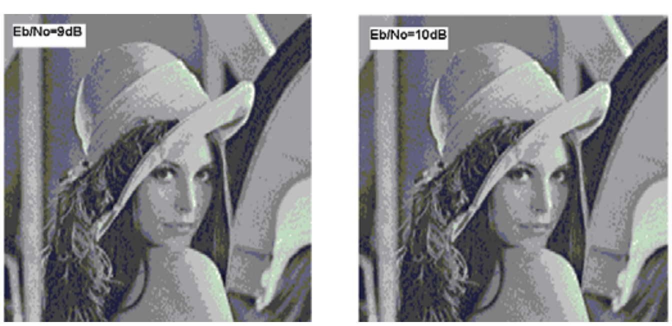

Fig. 5. Reconstructed images for AWGN Channel using PSK modulation with M=2 for E_b/N_o= 9dB and 10dB.

Fig. 6. Reconstructed images for AWGN Channel using QAM modulation with M=2 for E_b/N_o= 9dB and 10dB.

The plot shows that the performance of PSK modulation scheme with M=2 is the best as compared to all the other schemes.

Fig. 7. Reconstructed images for AWGN Channel using DPSK modulation with M=2 for E_b/N_o= 9dB and 10dB.

The performance of QAM with M=2 is comparable with that of PSK with the same order. This is supported by the reconstructed images as shown in fig. 5 – fig. 7.

The graphs (fig. 4) also show that the performance detoriates as the order of modulation is increased. For AWGN channel an E_b/N_0 = 9dB is sufficient to get back the original image.

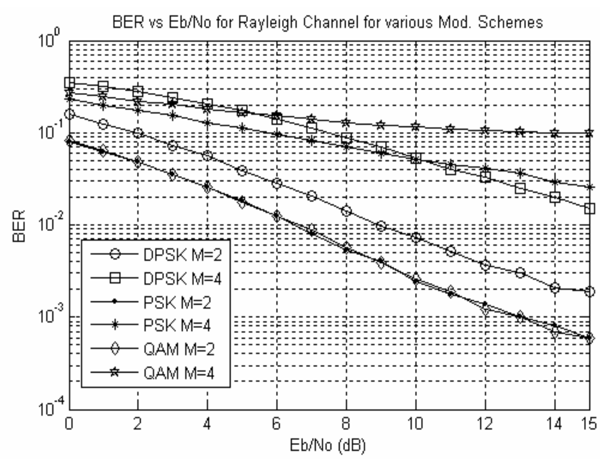

Fig. 8. BER versus E_b/N_0 for Multipath Rayleigh Channel (number of paths =3) with DPSK, PSK and QAM for M=2 and 4.

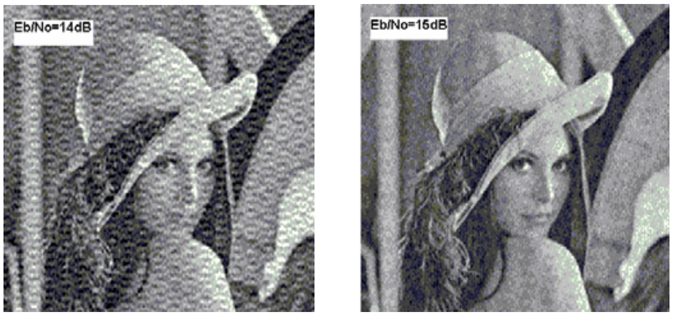

Fig. 9. Reconstructed images for Multipath Rayleigh Channel using PSK modulation with M=2 for E_b/N_o= 14dB and 15dB.

Similar BER graphs are plotted for multipath Rayleigh fading channel (number of paths =3) (fig. 8). It can be seen that the performance of PSK modulation scheme with M=2 is again the best.

Fig. 10. Reconstructed images for Multipath Rayleigh Channel using QAM modulation with M=2 for E_b/N_o= 14dB and 15dB.

It can also be seen that performance of DPSK scheme with M=2 is also somewhat acceptable at higher values of E_b/N_0 for both AWGN and Rayleigh fading channels.

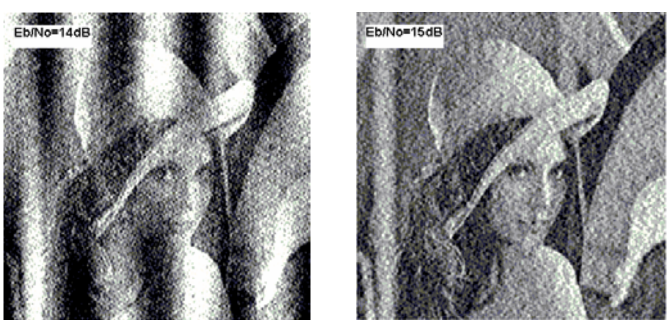

Fig. 11. Reconstructed images for Multipath Rayleigh Channel using DPSK modulation with M=2 for E_b/N_o= 14dB and 15dB.

Fig. 9 – Fig. 11 are the reconstructed images for rayleigh channel. The original image is the same as considered for AWGN channel (Fig. 3). As expected, due to effect of fading a larger value of E_b/N_0 (approximately 14dB) is required to obtain acceptable quality of reconstructed image.

V. Conclusion

Based on the above discussion we conclude that it is preferable to use a lower order modulation for transmission especially on fading channels. However for lower order modulation the bandwidth requirement is higher. A better option would be to adopt quadrature amplitude modulation schemes.

VI. Acknowledgment

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VII. References

[1] D. W. Lim, J. S. No, C. W. Lim, and H. Chung, "A New SLM OFDM Scheme With Low Complexity for PAPR Reduction," *IEEE Signal Processing Letters*, vol. 12, No. 2, pp. 93-96, Feb. 2005.

[2] M. R. Raghavendra, S. Bhaahyam, and K. Giridhar, "Exploting Hopping Pilots for Parametric Channel Estimation in OFDM Systems," *IEEE Signal Processing Letters*, vol. 12, No. 11, pp. 737-740, Nov. 2005.

[3] A. K. Katsaggelos, F. Zhai, Y. Eisenberg, and R. Berry, "Energy-Efficient Wireless Video Coding and Delivery," *IEEE Wireless Communications*, pp. 24-30, Aug. 2005.

[4] K. Murota and K. Hirade,"GMSK Modulation for Digital Mobile Radio Telephony," *IEEE Trans.Commun.*, Vol. COM-29, No. 7, pp. 1044-1050, July 1980.

[5] Y. Akaiwa and Y. Nagata, "Highly Efficient Digital Mobile Communications with a Linear Modulation Method, "*IEEE J. Selected Areas Commun.*, Vol. 5, No. 5, pp. 890-895, June 1987.

[6] Wallace and K. Gregory, "The JPEG Still Image Compression Standard," *Communications of the ACM*, Vol. 34(4), pp. 30-44, April 1991.

[7] Watson and Andrew,"Image Compression Using the Discrete Cosine Transform," *Mathematica Journal*, Vol. 4(1), pp. 81-88, 1994.

[8] S. Hara, K. Fukui, M. Okada, and N. Morinaga, "Multicarrier Modulation Technique for Broadband Indoor Wireless Communications," in *Proc. PIMRC '93*, Yokohama, Japan, pp. 132-136, Sept. 1993.

[9] J. G. Proakis, *Digital Communications*, 4^{th} ed., McGraw-Hill, New York, 2001, pp. 254-839.

[10] N. Maeda, S. Sampei, and N. Morinaga, "Performance of a Sub-carrier Transmission Power Controlled OFDM System for High Quality Data Transmission," in *PIMRC '99*, Osaka, Japan, pp. 368-372, Sept. 1999.

VIII. Biographies

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Nitin S. Nagori was born in Aurangabad, India in 1966. He completed his B.E. from Marathwada University in 1987. From 1995 to 1997 he was with Department of Telecommunication Engineering, D.N. Patel College, Shahda and from 1997 to 2000 with Gangmai College , Dhule as a Lecturer. Presently he is working in K. J. Somaiya College of Engineering, Electronics and Telecomunication Department as a Senior Lecturer. He has provided consultancy to several industries and is a life member of IETE (Institution of Electronics and Telecommunication Engineers). His current research interests include signal processing, control systems and communication networks.