SubCarrier Index - QAM, A New Hybrid Modulation Scheme for OFDM

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Abstract

In this paper, we present a new hybrid modulation scheme based on quadrature amplitude modulation (QAM) and the idea behind frequency shift keying (FSK) for multicarrier systems. The proposed scheme is a request based modulation scheme where the QAM modulated message signal bits are encoded to different subcarriers based on the message signal bits. This way the subcarrier index also carries some message signal bits without its physical transmission. Perfect utilization of all subcarriers is assumed. The proposed scheme shows considerable improvement in spectral efficiency.

Keywords: QAM, OFDM, Subcarrier Index.

1. Introduction

Due to the recent exponential increase in mobile traffic, new methods and techniques are to be developed to cope with the future requirements of high capacity. High throughput requirements force cellular technologies to the use of high density modulation schemes. 256-QAM is the suitable modulation candidate for LTE-Advance [2]. Such high density modulation schemes for OFDM based systems increases throughput but the same time increases the probability of bit error and peak to average power ratio (PAPR). Which is a practical limiting factor of OFDM based system [3].

OFDM uses a set of orthogonal subcarriers. Conventional OFDM encodes the constellation points from a PSK or QAM modulator onto these subcarriers. The proposed scheme transmits half of the message signal. The other half is recovered based on the subcarriers index. . The proposed

scheme is compared with conventional OFDM in terms of capacity, BER and PAPR. The rest of the paper is organized as, section 2 provides a brief introduction of the proposed scheme with its limitations and drawbacks. Conclusion is drawn in section 3.

2. SUB-CARRIER INDEX QAM

An OFDM system with 4 subcarriers and an extra subcarrier for side information is considered. The proposed encoder part before the inverse discrete Fourier transform (IDFT) is shown in Figure 1. The message signal is divided into packets of 4 bits. In each packet the first 2 bits are modulated by a 4-QAM modulator, the rest of the 2 bits are used for mapping the corresponding constellation point onto the corresponding subcarrier, without its physical transmission. Perfect utilization of subcarriers is assumed, which means in each frame all the subcarrier indices bits occurs once. But as the message bits are randomly generated message signal bits with Gaussian distribution of zero mean and zero variance. For N number of sub-carriers the resource utilization which is the probability of mapping a constellation point onto the subcarrier is given by equation below.

$$P_{mapping} = \frac{1}{N} \quad (1)$$

In our assumption $P_{mapping} = 1$. The total number of subcarriers including the subcarrier carrying side information is $N_p = N + 1$. As the constellation points are only mapped onto N subcarriers. The number of subcarriers are selected as $N = 2^\alpha$ where α is a positive integer. The minimum length U of binary mapping decision bits is calculated as below.

Fig. 1. Proposed scheme with 4 data, 1 side information subcarrier and with 4-QAM modulation

$$u = \log_2(N)$$

As the mapper maps the constellation points onto different subcarriers and distorts the original order of the

Fig 1. Proposed scheme with 4 subcarriers for data transmission and 1 subcarrier for side information.

constellation points. Some side information is sent to the receiver by an additional subcarrier to correctly generate the original message signal constellation sequence from the received signal. For a 4-QAM modulator, with 4 independent constellation points. The mapper can arrange the constellation points in different possible manners given by $factorial(4) = 24$. As the receiver needs some information to correctly rearrange the constellation points, for a 4-QAM with 4 subcarriers the minimum length of such side information bit is given by $N+I=4+I=5$.

2.1 CAPACITY OF SI-QAM

The capacity of a single conventional OFDM subcarrier with a bandwidth of 1Hz is given by the famous Shannon equation below.

$$C_{conv} = \log_2 \left(1 + \frac{E_b}{n_a} \right) \quad (3)$$

Where n_a is the noise power and E_b is the transmit signal bit energy. The capacity of the proposed scheme is given by Equation (4). Where u is the length of mapping decision bits, N is the number of subcarrier carrying the constellation points and N_p is the total number of subcarriers.

Fig. 2. Capacity comparison Subcarrier index QAM with 4 data and 1 side information subcarrier with conventional OFDM with 5 subcarriers

$$C_{pro} = \frac{u \times N}{N_p} \times C_{conv} \quad (4)$$

2.2 BER Calculation

Figures, As the spectral efficiency of the proposed scheme is same as 8-QAM. Its error performance is loosely speaking equal to 4-QAM, as the transmitted constellation points are from a 4-QAM modulator given by Eq (5) [4].

Spectral efficiency of the proposed scheme

$$P_e = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{2^{\sqrt{N}} - 1}{2^{\sqrt{N}-1}} \times \frac{E_b}{n_a}} \right)$$

Where N is the number of subcarriers carrying constellation points. For fair comparison of the proposed scheme bit error rate BER performance we compare it with 8-QAM as its spectral efficiency is the same as 8-QAM.

$$P_e = 2.59 \times \operatorname{erfc} \left(\sqrt{\frac{2^{\sqrt{N}} - 1}{2^{\sqrt{N}-1}} \times \frac{E_b}{n_a}} \right)$$

$$\frac{\sqrt{M} - 1}{\sqrt{M} \log_2(\sqrt{M})} = 2.59 \quad \text{for } M=8.$$

Equation (6) and (5) shows that the proposed scheme has better BER performance as compare to 8-QAM.

2.3 PAPR Performance

OFDM time domain signal has large envelope fluctuation due to its multicarrier nature. These multi carriers known as

Fig. 3. Proposed scheme with 5 subcarriers 4bps/Hz each subcarrier with conventional OFDM scheme 4bps/Hz each subcarrier.

sub-carriers can constructively add up and results in high peak power. The envelope fluctuation of OFDM signal is measured by performance metric peak to average power ratio (PAPR). High PAPR results in low amplifier

efficiency and thereby consumes more power, which makes it inefficient for battery operated devices. The PAPR for OFDM signal is given by Equation (7) [1]. Where M is the M -ary modulation scheme and N is the number of subcarriers used. The PAPR performance of the proposed scheme is compared with 8-QAM, $M=8$ as the proposed scheme is using 4-QAM but the spectral efficiency is the same as that of 8-QAM.

PAPR comparison of Conv-OFDM, with 4 subcarriers for data transmission with SI-QAM with 5 subcarriers, for spectral efficiency of 4bps/Hz on each subcarrier.

2.4 Limitations

As the message signal is random signal and the subcarrier is done on a request based on message signal. The probability of utilization becomes very low for a large number of subcarriers. The probability of utilization or probability of mapping P_{mapping} reduces considerably. If the constellation points are from higher modulation schemes like 8-QAM, the mapper can arrange the constellation points in factorial $(8)=40320$ ways. To rearrange the constellation point a binary data of 16bits must be sent as side information. For high density modulation schemes the amount of side information increases considerably

3. Simulation Results

The proposed scheme is compared with conventional OFDM with 5 subcarriers as data carrying subcarriers for conventional OFDM. The proposed scheme uses 5 subcarriers, 4 for data and one subcarrier for side information. The same modulation scheme 4-QAM is used for both the schemes. Figure (2) shows capacity calculation of both the schemes using computer simulations. Simulation results shows that the proposed scheme achieves better capacity as compare to conventional OFDM. The PAPR simulation results are shown in Figure (3). As PAPR is a random variable therefore it is shown by a cumulative distributive function (CDF) graph. Using Equation (5) a theoretical gain of 2dB can be achieved with the proposed scheme over conventional OFDM. The simulation results shows 0.5dB gain of the proposed scheme over the conventional OFDM scheme.

4. Conclusions

A new hybrid modulation scheme for OFDM based system is proposed. The proposed scheme is a request based scheme. Using 4-QAM the message data is converted to packets of 4 bits. The first 2 bits are modulated by the 4-QAM modulator the rest of the two bits are used as decision bits for mapping the said constellation point onto a subcarrier. The proposed scheme achieves high capacity than conventional OFDM using same number of subcarriers under perfect subcarriers utilization. And with low PAPR as compare to conventional OFDM with same capacity requirements. With increasing number of subcarriers the probability of utilization of a subcarrier reduces considerably. Our future work is to extend the algorithm to high density modulation schemes and find ways to increase probability of utilization or probability of mapping P_{mapping} .

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