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PERFORMANCE ANALYSIS OF OFDM WITH QUADRATURE AMPLITUDE MODULATION

E.Manimozhi[1], C.Mohanadevi[2]

[1]PG Student, Mailam Engineering College

[2]Associate Professor of ECE ,Mailam Engineering College

Abstract- **Recently, orthogonal frequency division multiplexing (OFDM) with index modulation (OFDM-IM) was proposed. Here fixed number of active subcarriers are selected to carry constellation symbols, & additional bits of information is carried by the indices of the active subcarriers. In this project, we propose OFDM with generalized index modulation 2 (OFDM-GIM2) using QAM technique. Quadrature Amplitude Modulation Technique is introduced to reduce bandwidth and transmission of more datas are achieved. Through such ways, a higher spectral efficiency than that of OFDM-IM may be achieved. Computer simulation results clearly show our proposed scheme OFDM-GIM2 with Quadrature Amplitude Modulation (QAM) superiority in both spectral efficiency and BER performance compared to existing works.**

Index Terms- **Bit Error Rate(BER), Quadrature Amplitude Modulation(QAM), Orthogonal Frequency Division Multiplexing(OFDM), Orthogonal Frequency Division multiplexing With Generalized Index Modulation(OFDM-GIM).**

I. INTRODUCTION

In recent years, multicarrier transmission has become an attractive technique in many wireless standards to meet the increasing demand for high data rate communication systems.One of the most popular multicarrier techniques, orthogonal frequency division multiplexing (OFDM).The major advantage of OFDM over single-carrier schemes is its ability to cope with frequency-selective fading channel with only one-tap equalizer. Spatial Modulationa technique originally implemented in (MIMO) transmissions, is one of the most promising techniques. In the Spatial Modulation scheme, besides the amplitude/phase modulations, the information may also be carried through the antenna indices. MIMO is fundamentally different from smart antenna techiques developed to enhance the performnce of signal data signal.

E.Manimozhi is a P.G student of Mailam Engineering College ,villupuram, Tamilnadu, India (corresponding author to provide phone: 9003327542; mail:manimozhi9@gmail.com).

C.Mohanadevi is ASSOCIATE PROFESSOR of Mailam Engineering College ,Villupuram, Tamilnadu, India (corresponding author to provide phone:9150338138; mail:devibalacm@gmail.com).

By treating the subcarrier indices of an OFDM system as the antenna indices in a MIMO system, Spatial Modulation has been successfully applied to OFDM. However, the scheme in seems to beimpractical because a perfect feedforward from the transmitter to the receiver needs to be assumed. Only in that way will the receiver know the mapping method for the subcarrier indexselecting bits. This feedforward requirement from the transmitter to the receiver has later been removed in, where an enhanced subcarrier index modulation OFDM (ESIM-OFDM) was proposed. Unfortunately, to achieve the same spectral efficiency as that of classical OFDM, this scheme needs to adopt higher order modulations.

Feedforward describes an element or pathway within a control system which passes a controlling signal from a signal source in its external environment, often a command signal from an external operator, to a load elsewhere in its external environment. In a feed-forward system, the control variable adjustment is not error based. Instead it is based on knowledge about the process in the form of a mathematical process & about measurements of the process disturbances. Here the disturbances are measured before they have time to affect the system.

Recently, a novel transmission scheme called OFDM with index modulation (OFDM-IM) has been put forward. The major contribution of this scheme is the utilization of subcarrier indices as a source of information so that the error performance of this scheme is significantly better than that of classical OFDM under frequency selective channels when BPSK is adopted. In addition, the spectral efficiency of this scheme under BPSK can exceed that of classical OFDM without increasing the size of the signal constellation because the indices of the active subcarriers carry information aswell.

Based on the technique in [1]. The generalization is proposed in two aspects. First,a more flexible selection of active subcarriers is proposed to further improve the spectral efficiency. However, the generalization in this aspect cannot fundamentally overcome OFDMIM’s difficulty in adopting QPSK symbols. In the second aspect of generalization, the in-phase component and quadrature component of QPSK symbols are split into two

independentcomponents so that index modulation is applied independently on these two components.
Based on the technique Orthogonal Frequency Division Multiplexing with Generalized Index Modulation2 using QAM technique is proposed. This proposed system results higherspectral efficiency than that of OFDM-IM may be achieved.
The rest of the paper is organized as follows. In Section II, the system model of OFDM-IM is reviewed. In Section III, we propose the second generalization scheme of OFDM-IM. Then OFDM-GIM 2 with QAM Technique is given in Section IV. Section V analyzes the implementation complexity of OFDM-GIM2. The simulation results are presented in Section VI. Finally, Section VII concludes the paper.

II. REVIEW OF OFDM-IM

In this scheme, incoming B bits are transmitted per OFDM frame over a frequency selective Raleigh fading channel. First, the incoming B bits are divided into Ggroups and every group has p bits, i.e., B = pG.Every group of p bits. Every p bits are divided into two parts p1,p2. Christo Ananth et al. [4] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing. The proposed system has a fuzzy filter which has the parallel fuzzy inference mechanism, fuzzy mean process, and a fuzzy composition process. In particular, by using no-reference Q metric, the particle swarm optimization learning is sufficient to optimize the parameter necessitated by the particle swarm optimization based fuzzy filter, therefore the proposed fuzzy filter can cope with particle situation where the assumption of existence of "ground-truth" reference does not hold. The merging of the particle swarm optimization with the fuzzy filter helps to build an auto tuning mechanism for the fuzzy filter without any prior knowledge regarding the noise and the true image. Thus the reference measures are not need for removing the noise and in restoring the image. The final output image (Restored image) confirm that the fuzzy filter based on particle swarm optimization attain the excellent quality of restored images in term of peak signal-to-noise ratio, mean absolute error and mean square error even when the noise rate is above 0.5 and without having any reference measures.Assume that there are K active subcarriers for K n. Thus, the incoming p bits are divided into two parts. The first part has p1 bits and the second part has p2 bits i.e.,p = p1 + p2, as shown in Fig.1.The dashed block is named as the index modulation block in this paper. The p1 bits are fed to the index selector, mapping the incoming p1 bits to a combination of K active subcarriers, i.e., Igfor 0<g<G. Denote the K indices of the active subcarriers of theg-th OFDM subblock as,

$$I^g = fi_1{}^g; : : : ; i_K{}^g\ g ; \qquad (1)$$

(1)

where $i^g{}_k$ 2 [1; : : : ; n] for g = 1; : : : ; G, k = 1; : : : ; K and $i^g{}_{k1}$ 6= $i^g{}_{k2}$ if k_1 6= k_2.

On the other hand, the p2 bits of the g-th OFDM subblock go through the M-ary mapper (modulator) to be mapped to K signal constellation symbols. The output of the mapper are given by

$$s^g=\{s_1{}^g,....,s_k{}^g\}, \qquad (2)$$

where $s_k{}^g$ € s for g = 1; : : : ;G, k = 1; : : : ;K and S is the set of M-ary constellation symbols. Hence, the maximum number of bits that can be carried by the selection of K active subcarriers is given by,

$$B_1=p_1G=[\log_2 C_n{}^k]G \qquad (3)$$

where$C_n{}^k$denotes the number of K combinations from a given set of n elements. The maximum number of bits carried by the K M-ary signal constellation symbols is,

$$B_2=p_2G=[\log_2 M]G \qquad (4)$$

As a result the maximum number of bits that can be transmitted by a single block of OFDM-IM scheme is

$$B_1+B_2=[\log_2 C_n{}^k]G+(\log_2 M)G$$
$$=[\log_2(M^k C_n{}^k)]G \qquad (5)$$

For the K active Subcarriers in an OFDM subblock, the signal constellation is normalized to unit average power by setting,

$$E\{s^g s^{gH}\}=K \qquad (6)$$

Where $(.)^H$ stands for Hermitian transposition. The N×1 OFDM block is then built up by

$$X=[X(1),X(2),...,X(N)]^T, \quad (7)$$

where X(α) € {0,S} for α= 1,..,N, i.e., each subcarrier is either active carrying a signal constellation, or inactive carrying zero.
Next, the IFFT (or FFT for the receiver) algorithm is implemented, where a normalization factor N/√Ktot (or √Ktot/N) is applied to ensure that the input to the IFFT (or the output of FFT) x satisfies $E\{x^H x\}$=N.Here Ktot = GK is the total number of active subcarriers within the OFDM

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block. Assume that a frequency-selective Rayleigh fading channel, represented by its channel impulse response (CIR) coefficients, is given by,

$$h=[h(1),h(2),..,h(V)]^T, \quad (8)$$

Where h(v), for v=1,...,V, follows the complex Gaussian distribution CN(0,1/V) and V is the number of paths. Assuming further that the channel remains constant during the transmission of an OFDM block and the length of cyclic prefix (CP), L, is larger than V. The output of the FFT algorithm atthe receiver, Y (α), is given by

$$Y(\alpha)=X(\alpha)H(\alpha)+W(\alpha), \quad \alpha=1,...,N \quad (9)$$

Where H(α) are the channel fading coefficients, W(α) denote the frequency domain channel samples with the distribution of $CN(0;N_{0;F})$ and $N_{0;F}$ is the noise variance in the frequencydomain. The relationship between the noise variance in time domain, denoted as $N_{0;T}$, and that in frequency domain is given by

$$N_{0,F}=(k_{tot}/N)N_{0,T} \quad (10)$$

Unlike classical OFDM, in the OFDM-IM scheme the receiver not only need to detect the information bits on the active subcarriers, but also need to detect the indices of the active subcarriers. For any subcarrier, the metric of determining whether this subcarrier is active is to investigate what kind of frequency domain symbols it is carrying. Specifically, if it is carrying a non-zero symbol, then it is active. Otherwise, it is inactive. Two different types of detectors, i.e., Maximum Likelihood (ML) detector and Log-likelihood Ratio (LLR) detector have been proposed. Compared to ML detector, LLR Detector has a much lower decoding complexity and is more suitable for higher C_n^k. In [1], the LLR detector evaluates the logarithm of the ratio of a posteriori probabilities of non-zero to that of zero for every subcarrier. This ratio providing the information about the active status of the corresponding subcarrier, is formulated as

$$\lambda(\alpha) = \ln(K) - \ln(n-k) + |Y(\alpha)|^2/N_{0,F} + \ln (\Sigma_{m=1}^{M} \exp (-1/N_{0,F}|Y(\alpha) - H(\alpha)s_m|^2)) \quad (11)$$

where α = 1,...,N, S_m € S. The larger the value of λ(α) the higher the probability that the subcarrier transmitting Y (α) is active. Demodulation of the constellation symbols on the active indices is then straightforward.

III. THE SECOND GENERALIZATION SCHEME OF OFDM-IM

OFDM-IM successively increases the transmitting spectral efficiency and meanwhile improves the BER performance for signals with high SNR under BPSK symbols. However,OFDM-IM becomes ineffective when higher constellation symbols other than BPSK are implemented. For example,when M-ary constellation symbols are implemented, for a certain n and K, the total number of bit combinations that OFDM-IM can represent is given by $M^kC_n^kG$. However, to achieve the same spectral efficiency as classical OFDM using QPSK, the total number of combinations required is M_nG.

$$\frac{M^n G}{M^k C_n^K G} = \frac{M^{n-K}}{C_n^K} > 1 \quad (12)$$

Noting thatfor most choices of n and K when M ≥ 4, it is important to find schemes to remedy this shortcoming of OFDM-IM. Compared to classical OFDM using BPSK, classical OFDM using QPSK doubles the spectral efficiency with no BER performance loss. The generalization technique proposed it mitigates the problem by further improving the spectral efficiency with marginal BER performance loss. However, the proposed OFDM-GIM1 cannot fundamentally solve the problem for QPSK symbols. The second generalization of OFDM-IM, aiming at QAM constellation symbols, is introduced in this section. This scheme is based on the original OFDM-IM and named as OFDM-GIM2.

A. Main Idea

In wireless communication, an M-arycomplex constellation symbol (for M _ 4) consists of an in-phase component and a quadrature component. In [1], the in-phase and quadraturecomponents are regarded as inseparable and index modulation is applied coherently to the complex constellation symbol as a whole. In other words, in the original OFDM-IM, ifa subcarrier is inactive, both the in-phase and quadrature components carried are 0, and if a subcarrier is active, both the in-phase and quadrature components carried are non-zero. The basic idea of our proposed generalization approach is to split the in-phase component and quadrature component into two independent components so that index modulation is appliedindependently on these two components, i.e., a subcarrier is not necessary to be active or inactive simultaneously for the in-phase and quadrature components.

For QPSK, the in-phase and quadrature component can be regarded as two independent BPSK streams. If two independent index modulations are applied to these two independent BPSK streams, the total number of combinations that can be represented is given by

$$2^kC_n^k2^kC_n^kG=4^kC_n^kC_n^kG. \quad (13)$$

On the other hand, the total combination that OFDM-IM using QPSK represents is $4^kC_n^kG$. As a result, we have

$$4^kC_n^kC_n^k > 4^kC_n^kG \quad (14)$$

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For example, when n=16, K=10, the total number of bits that our scheme can transmit is given by

$$([\log_2 2^{10}C_{16}^{10}] + [\log_2 2^{10}C_{16}^{10}])\ G = 44G \quad (15)$$

While the total numbers of bits that OFDM-IM and OFDM can transmit are both

$$([\log_2 4^{10} c_{16}^{10}])\ G = ([\log_2 4^{n}])\ G = 32G \quad (16)$$

In other words, when n = 16;K = 10, our proposed OFDM-GIM2 offers a 37.5% higher spectral efficiency compared to OFDM-IM. To successfully implement our proposed scheme, several changes are necessary and will be introduced in the following two sections.

B. Revised Index Modulation Block

Different from OFDM-IM, at the transmitter, the input bit strings allocated to each subblock are equally split into two parts, one for in-phase components' index modulation and the other for quadrature components' index modulation. Frequency response is the measure of the magnitude and phase of the output as the function of frequency, in comparison to the input. Theoutputs of these two index modulation are then combined into a complex M-ary constellation symbol. The output of these two index modulations are allocated the same total power such that the combined complex M-ary constellation symbol vector x still satisfies $E\{x^H x\} = N$.

C. Revised LLR detector

The revised LLR detector for OFDM-GIM2 should have zero-forcing equalization first. For the α-th frequency domain received signal Y (α), for α = 1,...,N. let

$$Y^{"}(\alpha) = \frac{Y(\alpha)}{H(\alpha)} \quad (17)$$

Note that the zero-forcing equalization amplifies the noise power so the noise power in should be changed accordingly by introducing a factor of $H^2(\alpha)$. After equalization, what the detectors will detect ares_m € S instead of Hs_m. Zero forcing equalisation applies the inverse of the channel frequency response to the received signal to restore the signal after the channel.It brings the intersymbol interference to zero in the noise free case.Therefore, the revised LLR detector for the in-phase component is derived.

IV OFDM-GIM2 WITH QAM TECHNIQUE

Bit splitter divides the incoming b bits into groups. Every group has p bits. Thus, the incoming p bits are divided into two parts. First part has p1 bits and second part has p2 bits. The p1 bits are fed into the index selector, mapping the incoming p1 bits to a combination of active subcarriers. On other hand p2 bits go through M-ary mapper to be mapped to signal constellation symbols. N-point FFT represents the number of sampled points taken for computation. A cyclic prefix is a repetition to the first section of a symbol that is appended to the end of the symbol. In addition it is important because it enables multiple representations of the original signal to fade so that they do not interfere with the subsequent symbol.

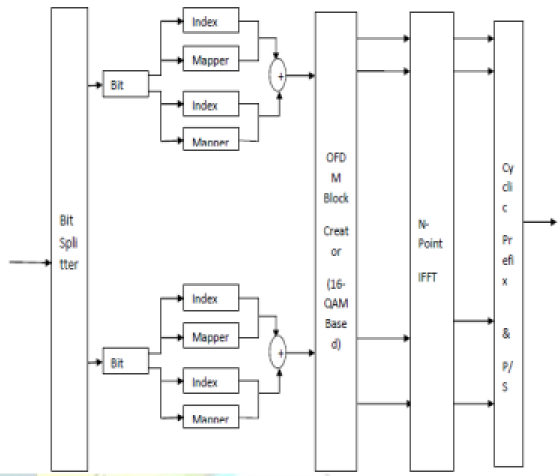

Fig.1.Block Diagram of proposed OFDM transmitter

Once the cyclic prefix has been added to the subcarrier channels, they must be transmitted as one signal. Thus the parallel to serial conversion stage is the process of summing all the sub-carriers and combining them into one signal. As a result, all subcarriers are generated perfectly simultaneously.

In receiver side the generated subcarriers are sent to the serial to parallel converter & cyclic prefix, here it removes the redundancy, and serial bit streams are converted to parallel bit streams to avoid the overlap between the symbols. And the converted symbols are sent to the N-Point FFT it converts frequency domain to time domain and sent it is sent to OFDM block here quadrature amplitude demodulation takes place and sent to LLR detector. LLR detector , detects the active subcarriers and the M-ary constellation symbols. After the calculation of LLR values, the subcarriers with highest probabilities are said to be active. The set of active indices are passed to the index demapper, it performs the inverse action of index selector block. Finally all the bits are combined in the bit combiner and generated as the single signal.

QAM is a method of combining two amplitude modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. QAM is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing the amplitudes of two carrier waves , using the amplitude shift keying (ASK). The two carrier waves, usually sinusoids, are out of phase with each other by 90 degree and are thus called asquadrature carriers or quadrature components. The modulated waved are summed and the final waveform is a

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combination of both phase shift keying (PSK) and amplitude shift keying (ASK). In digital QAM case, a finite number of atleast two phases and atleast two amplitude are used. PSK modulators are often designed using QAM principle, but are not considered as QAM since the amplitude of the modulated carrier signal is constant. QAM is used extensively as a modulation scheme for digital telecommunication systems.

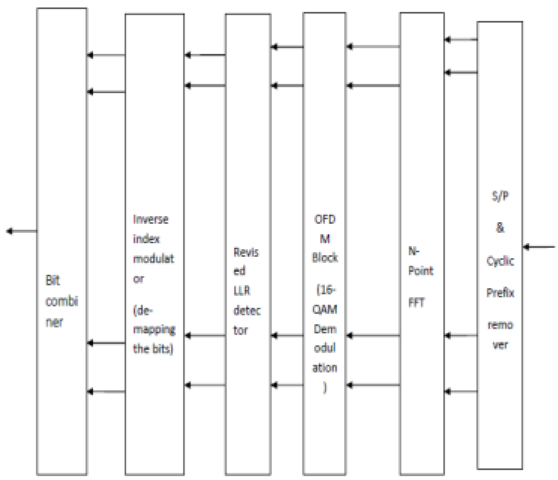

Fig.2. Block Diagram of OFDM receiver.

QAM is used in a variety of communications systems such as dial up modems and WIFI. In cable systems, a QAM tuner is linked to the cable in manner that is equivalent to receive an ATSC tuner which is required to receive over-the-air (OTA) digital channels broadcast by local television stations when attached to an antenna. Arbitrarly high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, limited only by the noise level and linearity of the communications channel. QAM is being used in optical fiber systems as bit rates increase, QAM 16 and QAM 64 can be optically emulated with a 3-path interferometer.

V IMPLEMENTATION COMPLEXITY OF OFDM-GIM2

For our proposed two generalization schemes, the major difference of implementation complexity compared to that of lies in the computational complexity of the upgradedLLR detectors. For OFDM-IM, the complex multiplications is ≈O(M) per subcarrier when M-ary constellation symbols are carried.For OFDM-GIM2, the complex multiplications is ≈O(2M) per subcarrier. The value 2 here indicates the complexity of the independent detections for in-phase and quadraturecomponents.

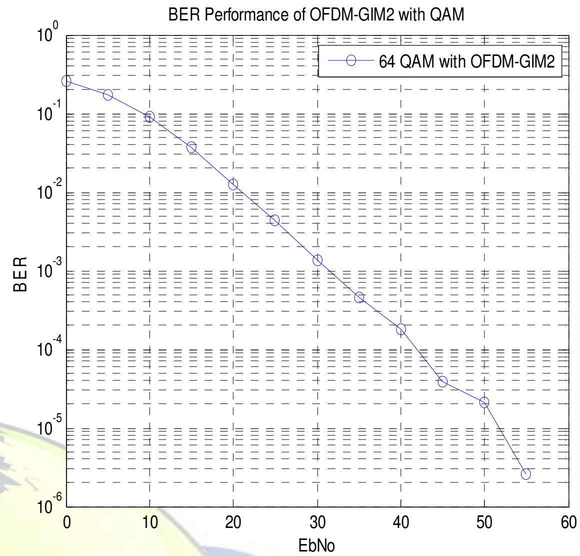

Fig.4. simulation result of BER performance

VI SIMULATION RESULTS

The simulation results of the proposed schemes are shown and compared with that of OFDM-IM under frequency selective channels. In all simulations, we assumed the same system parameters as in [1] and [23], i.e., N = 128; V = 10 and L = 16: The SNR is defined as Eb=N0;T, where Eb= (N + L)=B is the average transmitted energy per bit. The BER performance of these schemes was evaluated via Monte Carlo simulations. Fig. 4 shows the BER performances of the OFDM-GIM1 schemes with two different K sets, classical OFDM and OFDM-IM for BPSK. The subblock size n is set to 8. When K = f3; 5g, according to (16), it is known that 11 bits can be transmitted per subblock. However, for OFDM-IM with n = 8, only 10bits can be transmitted per subblock. Our proposed OFDM-GIM1 scheme achieves 10% higher spectral efficiency [1] at the cost of a BER performance loss lower than 0.5 dB. When K = f1; 2; 3; 4; 5; 6g, according to (16), 12 bits can be transmitted per subblock, and thus a 20% higher spectral efficiency is achieved at the cost of a BER performance loss up to 2.5 dB. The 2.5 dB BER performance loss was observed at the BER probability of 10□3.

VII CONCLUSION

In this paper, two generalization schemes of OFDM-IM are presented. To implement these two schemes, generalized index modulation blocks and upgraded LLR detectors are proposed, respectively. Interleaving is introduced to improve the BER performance of our proposed schemes in low SNR region. Both generalization schemes achieve higher spectral efficiency than OFDM-IM. When the same spectral efficiencies are considered, our proposed generalization schemes show consistent BER performance gain in all SNR regions. We also demonstrate that the two

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generalization schemes are compatible with each other and their combined scheme greatly outperforms existing works in spectral efficiency and BER performance, at the cost of a little higher complexity.

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