Haar Wavelet-Based OFDM System With Reduced Paper for Different Modulation Techniques Bitra

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Abstract

In Orthogonal Frequency Division Multiplexing(OFDM) based systems, with the increasing demand for data rate and reliability in Wireless communicationsand devices, several issues become very important like bandwidth efficiency, quality of service and radio coverage. The subcarriersalready occupied by the primary users cannot be used by the secondary users. This leads to possibly non-contiguouspositions of the available subcarriers for the secondary users.The conventional pilot design methods are no longer effectivefor such systems. This paper proposes a novel BPSK OFDM system based on Haar wavelet transformation. The Haar wavelet transformation operates decompositionover the data symbol sequence after binary-to-complex mapping shows that half of the datasymbols are zeros and the rest are either√2 or −√2. Then, we have the PAPR reduced by10 log10 2 ≈ 3 dB at most, compared with the conventional OFDM system. We also proposed novel decoding algorithm for the proposed OFDM system to show robustness to spectralnull channels, and derive the bit error rate (BER) performance in theory from modulation. Finally, With the OFDM concept we improve the bitrate and BER of theoverall system.Simulation results show that thepilot index sequences obtained by the proposed method exhibitsignificantly better performance than those obtained by existing pilot design methods.

Keywords

OFDM, Peak-to-average Power Ratio (PAPR), Bit Error Rate (BER), Haar Wavelet, MIMO

I. Introduction

Wireless digital communication is rapidly expanding, resulting in a demand for wirelesssystems that are reliable and have a high spectral efficiency. Orthogonal Frequency Division Multiplexing (OFDM) has been considered as a promising candidate to achieve high ratedata transmission in a mobile environment. Recently, OFDM has become the technique ofchoice for several popular broadband applications, such as Asymmetric Digital Subscriber Line(ADSL) modems, Digital Audio Broadcasting (DAB) [1], Digital Video Broadcasting (DVB) [2-3] and Wireless Local Area Networks (WLAN) systems (IEEE 802.11a [4], IEEE 802.11g[5]).

However, due to the large number of subcarriers used, OFDM systems have a large dynamicsignal range with a very high peak-to-average power ratio (PAPR). As a result, the OFDM signal will be clipped when passed through a nonlinear power amplifier at the transmitter end.Clipping degrades the bit-error-rate (BER) performance and causes spectral spreading. Oneway to solve this problem is to force the amplifier to work in its linear region [6]. In high speeddigital wireless applications, however, the Inter-Symbol Interference (ISI) channel may havespectral nulls, which may degrade the performance of the existing OFDM systems because the Fourier transformation of the ISI channels needs to be inverted for each subcarrier at theOFDM receiver [7]. Hence, PAPR and spectral null channels need to be properly handledin implementation of OFDM systems [8], which are crucial for the performance of areal system.

The Wavelet-OFDM system was widely studied in [9-10]. However, Wavelet-OFDMjust substitutes the DFT and IDFT with DWT and IDWT, respectively. The Wavelet-OFDMwas studied to show robustness to Doppler [9]. In this paper, we propose a novel Haar wavelet-based BPSKOFDM system. Since the data symbol produced by BPSK modulator iseither 1 or−1, the Haar wavelet transformation operates decomposition over the data symbolsequence after binary-to-complex mapping shows that half of the information symbols arezeros and the rest are either√2 or −√2. Then, the proposed BPSK-OFDM has the PAPRreduced by 10 log10 2 ≈ 3 dB at most, compared with the conventional OFDM system. Wealso propose a novel decoding algorithm for our proposed OFDM system to show robustnessto spectral null channels. Simulations and theory analysis are conducted to illustrate ouranalysis correctness.

Henceexploiting the spatial diversity of the wireless environment by using Multiple Input Multiple Output (MIMO) expands the system capacity (higher data throughput)and it combat the faded channel effectively. It has been shown in the literature [10] that the capacity of a single transmits antennas system increases logarithmicallywith the number of receive antennas. Meanwhile, the capacity of a MIMO systemwith equal number of transmitters and receivers increases linearly. ImplementingMIMO leads to improvement in the data transmission reliability (very lowBER). MIMO is the most effective technique to accomplish reliable communicationthrough the wireless channel where the receiver is provided with independently faded replicas of the transmitted signal. These advantages are achievable without any increase of the transmitted power or expansion of the bandwidth.Several independent signals are transmitted from several antennas.

In this paper, we assume no frequency offset and channel impulse response (CIR) is givenin our OFDM – MIMO system like our previous work [11–13]. The impact of ICI on OFDM systemperformance is widely discussed in [14-15]. Since the ICI exists in the real application system,we will jointly consider different digital modulations and wavelets to analysis the ICIimpact and theoretical BER performance in our next research work. The CIR is usually estimatedusing feedback information, and different estimators (i.e., ML, MMSE) are proposedfor CIR estimation.

The rest of the paper is organized as follows. In Sect. 2,(a) we present the Haar wavelet-based BPSK OFDM system,(b) we study the PAPR performance of the proposed OFDM system and (c) we present a novel decoding algorithm and derive the BER performance ofour proposed OFDM – MIMO system. In Sect. 3, the theoretical and simulation results are presentedto illustrate our theory analysis correctness.

II. System Design Model

A. Haar Wavelet-Based BPSK OFDM System

In this section, we propose a novel Haar-wavelet based BPSKOFDM system. It is formulated as follows, which is the goal of this section.

1. Haar Wavelet Transformation

The oldest and most basic wavelet system is named Haar wavelet that is a group of squarewaves with magnitude of ±1 in the interval [0,1). In other words, the Haar functions are defined on the interval [0, 1) as

$$\varphi_0(t) = \begin{cases} 1, & \text{for } 0 \le t < 1 \\ 0, & \text{otherwise} \end{cases}$$

$$\varphi_1(t) = \begin{cases} 1, & \text{for } 0 \le t < \frac{1}{2} \\ -1, & \text{for } \frac{1}{2} \le t < 1 \\ 0, & \text{otherwise} \end{cases}$$

All the other subsequent functions are generated from ϕ1(t), which meanswhere i = 2 j + k, j ≥ 0 and 0 ≤ k <2 j . We have noticed that all the Haar wavelets are orthogonal to each other. From the Haar functions, we obtain the scale equation and wavelet equation as above.

The proposed Haar wavelet-based BPSKOFDM system structure is shown in fig. 1. We cansee from fig. 1 that the proposed system only increases Haar wavelet transformation at thetransmitter compared with the conventional OFDM system.To the best of our knowledge, there isn't any literature adds Haar wavelet transformation into conventional OFDM system directly, although some literatures use wavelet transformationto substitute the Fourier transformation unit, which is different from our paper.

Our Haar wavelet-based BPSKOFDM system has many advantages over the conventionalOFDM system. The advantages of our proposed OFDM system are obtained from the Haar wavelet transformation. The Haar wavelet transformation unit in fig. 1 operates decomposition over the inputdata symbol sequence after binary-to-complex mapping.

We denote the input data symbolas ˜ x(n) = [x(0), x(1), . . . , x(N − 1)]T , and the decomposition result is ˜ x_(n) =_x_(0), x_(1), . . . , x_(N − 1)_T . Since the input N by 1 vector sequence ˜ x(n) is produced byBPSK baseband modulator, each component of ˜ x(n) is either 1 or −1. The detail process of Haar wavelet decomposition over ˜ x(n) = [x(0), x(1), . . . , x(N − 1)].Since the Haar wavelet transformation is added in conventional OFDM system, the computationalcomplexity will increase. However, the Haar wavelet transformation is simply tooperate at the transmitter.

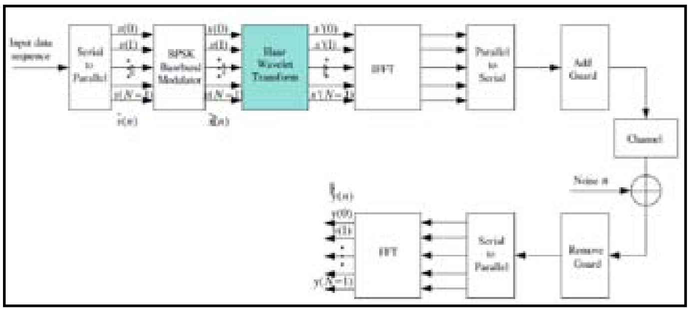

Fig. 1: The Haar Wavelet-based BPSK OFDM System

B. PAPR Performance

In this section, we study the PAPR benefits of the OFDM system. In OFDM system,PAPR is the peak power per OFDM symbol versus the average power in the same symbol, i.e., mathematically

$$\text{PAPR} = \frac{\max |x(t)|^2}{E\left\{|x(t)|^2\right\}}$$

Suppose that the average power of the conventional OFDM system is .POFDM with thesignal peak value AOFDM and the average power of the Haar wavelet-based BPSK OFDM system is PDWT/OFDM with the signal peak value ADWT/OFDM. The average power of theconventional OFDM and the proposed OFDM system is equal for every frame, which can be derived from Parseval theorem, which means

$$\bar{P}_{\text{DWT/OFDM}} = \bar{P}_{\text{OFDM}}$$

Since the Haar wavelet transformation used in our proposed OFDM system, half of theinformation symbols are zeros and the rest are either√2 or −√2 in each OFDM symbol.Hence, non-zero symbols in Haar wavelet-based BPSKOFDM system only occupies half ofthe subcarriers and the magnitude of each symbol is√2 times compared with conventionalOFDM system. Considering the worst situation (all subcarriers appear themaximal value at the same time), we get

$$\frac{A_{\text{DWT/OFDM}}}{A_{\text{OFDM}}} = \frac{\sqrt{2} \times \frac{N}{2}}{N} = \frac{\sqrt{2}}{2}$$

$$\left(\frac{A_{\text{DWT/OFDM}}}{A_{\text{OFDM}}}\right)^2 = \frac{1}{2}$$

Where N is the number of subcarriers in OFDM system. The peak power of the Haar wavelet-based BPSK OFDM system is reduced by half, compared with the conventional OFDM system. So Haar wavelet-based BPSK OFDM system's peakaverage power ratio (PAPR) is reduced by 10 log10 2 = 3dBatmost, compared with the conventionalOFDMsystem. Hence, the proposed Haar wavelet-based BPSKOFDM system is able to overcome the drawback of conventional OFDM system, with lower peak-average power ratio.Next, we present our empirical study characterizing the PAPR benefits via cumulative distribution functions, assuming N =1,024 subcarriers.

C. MIMO Model

The MIMO-based CR system under consideration is shown in Fig.1. The pilots are designed according to the result ofthe spectrum sensing. After subcarrier assignment where the subcarriers occupied by the primary users are deactivated,pilot symbols are inserted and the data are modulated onthe remaining activated subcarriers.We employ the MIMO concept in our simulation platform because it has beenproven that MIMO can achieve a major breakthrough in providing reliable wireless communication links. This reliability is in the context of the channel estimationin our case. With the MIMO concept we improve the bitrate and BER of theoverall system. MIMO is capable of this improvement, because of the property ofmultiple transmission multiple reception. This property is a form of spatial diversity.This diversity is the most effective technique to accomplish reliable communication over the wireless channel and combating with fading, because it providesthe receiver with multiple copies of the transmitted signal. Those multiple copiesare independently faded. If at least one copy of the transmitted signal is received correctly, we will have the transmitted signal back. This property improves the BER significantly (low BER) as shown in chapter 6. Beside this, MIMO increases thechannel capacity also, which means more throughputs. There are different ways toexploit multiple antennas at both sides of the communication channel. To improvethe transmission reliability, the transmit antennas should be used such that transmitdiversity is achieved. The transmission rate is comparable to the one obtainedin SISO. To improve the transmission rate, independent signals are transmittedfrom the different transmit antennas. i.e. there is no correlation between the transmittedsignals from the different antennas. In this case the reliability is not much improved.

$$y_r(t)=\sum_{k=0}^{K-1}\sum_{i=1}^{M}h_{i,r}^{(k)}(t)s_i(t-k)+n_r(t) \qquad (1)$$

Where si(t) is the transmitted signal from antenna i at time t, h(k) i,r(t) is the channel coefficient for the kth path from transmit antenna i to receive antenna r at time t. nr(t) is the Additive White Gaussian Noise. For mobile communications, the channel tap coefficients are random variables. In case the wireless channel varies very slowly, the tap coefficients remain constant for each frame of data. For Rayleigh fading channels, the channel tap coefficients are modeled as complex Gaussian random variables which have zero mean. The different channel taps are assumed to be independent. The average channel gains for different paths are determined from the power Delay profile of the wireless channel. In this work we assume that the channel tap powers decays exponentially. Hence we use the exponential power delay profile. If the MIMO-OFDM system has Nc subcarriers and the fading coefficients are spatially uncorrelated and that the fading coefficients remain constant during one OFDM symbol. Then the transmitted signal over M antennas can be represented by a matrix XOFDM with dimensions NcxM. A symbol transmitted at subcarrier n on transmit antenna is xi (n).

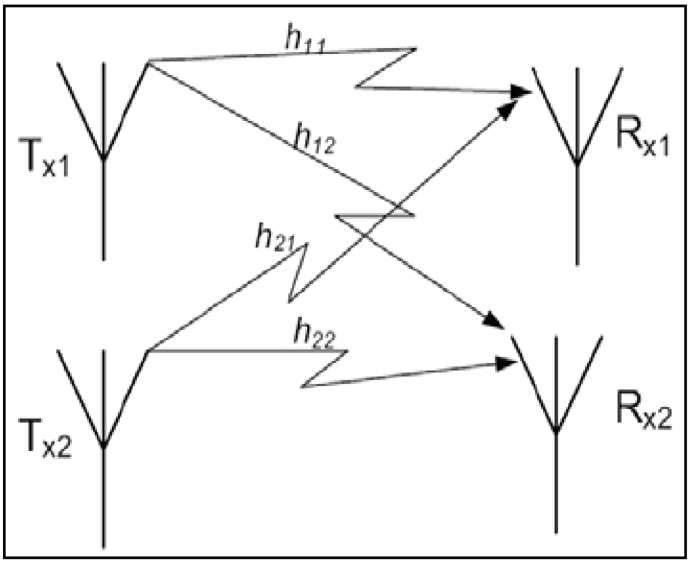

Fig. 2: MIMO Setup

At the receiver after applying FFT and removing the cyclic prefix, the resulting signal at the jth receive antenna for the n^{th} subcarrier will be:

$$y_r(n)=\sum_{i=1}^{M}x_i(n)H_{i,r}(n)+n_r(n) \qquad (2)$$

Where $H_{i,r}(n)$ is the channel coefficient from the ith transmit to the rth receive antenna for the nth subcarrier and is given by:

$$H_{i,r}(n)=\sum_{k=0}^{K-1}h_{i,r}^{(k)}e^{-j2\pi nk/N_c} \qquad (3)$$

where we can denote the channel coefficients for the (i, r)th links by:

$$H_{i,r}=\left[H_{i,r}(0)H_{i,r}(1).....H_{i,r}(N_c-1)\right] \qquad (4)$$

The vector of K independent fading coefficients of the different taps can be represented by:

$$A_{i,r}=\left[h_{i,r}^{(0)}h_{i,r}^{(1)}.......h_{i,r}^{K-1}\right] \qquad (5)$$

Hence we can see that the equivalent channel coefficients are:

$$H_{i,r}=WA_{i,r} \qquad (6)$$

Where W is the FFT matrix. In (6) the fading coefficients for distinct subcarriers are different but dependent. The maximum rank of the (frequency domain) channel matrix is equal to the number of taps K, and is usually low. The time domain signals at the receive antennas can be represented as:

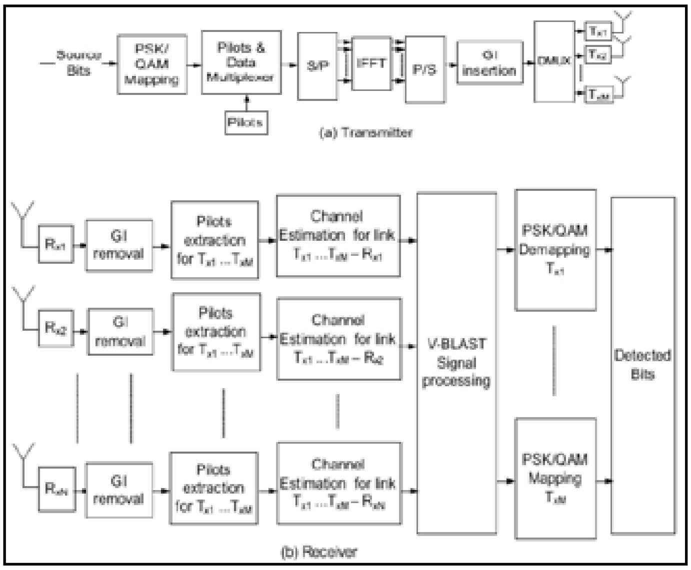

Fig. 3: MIMO System model (a) Transmitter and (b) Receiver

$$\begin{aligned} y_1 &= s_1 * CIR_{11} + s_2 * CIR_{21} + n_1 \\ y_1 &= s_1 * CIR_{12} + s_2 * CIR_{22} + n_2 \end{aligned} \qquad (7)$$

Where y_1 and y_2 are the vectors received by receive antennas R_{X1} and R_{X2} respectively. The transmitted signal vectors by transmit antennas T_{X1} and T_{X2} are represented by s_1 and s_2 where all variables are in time domain. CIR_{11}, CIR_{12}, CIR_{21} and CIR_{22} are the channel impulse responses of the different sub-channels, while n_1 and n_2 are the noise vectors (AWGN) with zero mean on the two receive antennas. Those two noise vectors are independent of each other. Putting (3.28) in matrix form gives:

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix}=\begin{pmatrix} CIR_{11} & CIR_{12} \\ CIR_{21} & CIR_{22} \end{pmatrix}\begin{pmatrix} s_1 \\ s_2 \end{pmatrix}+\begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \qquad (8)$$

Taking the FFT of the CIR gives the frequency domain channel matrix CTF as:

$$CTF_{2X2}=\begin{pmatrix} CTF_{11} & CTF_{21} \\ CTF_{12} & CTF_{22} \end{pmatrix} \qquad (9)$$

III. Simulation Results

In this section, we provide the theoretical and simulation results of the BER versus SNR for
(1) The conventional OFDM system and (2) the proposed Haar wavelet-based BPSKOFDM system. We consider 1,024 subcarriers, i.e.=1,024, and assume that BPSK modulation is used in the conventional OFDM and proposed OFDM system.

We consider the following twofixed ISI channels.Channel A: h = [0.407, 0.815, 0.407], which is a spectral-null channel.Channel B: h = [0.8, 0.6], although it does not have spectral-nulls, its Fourier transformvalues at some frequencies are small.The channels' characteristics (channel gains) are plotted in fig. 3. In addition, in figs. 4 and 5, we have shown the comparison of the BER performance between the conventionalOFDM system and the proposed OFDM system.

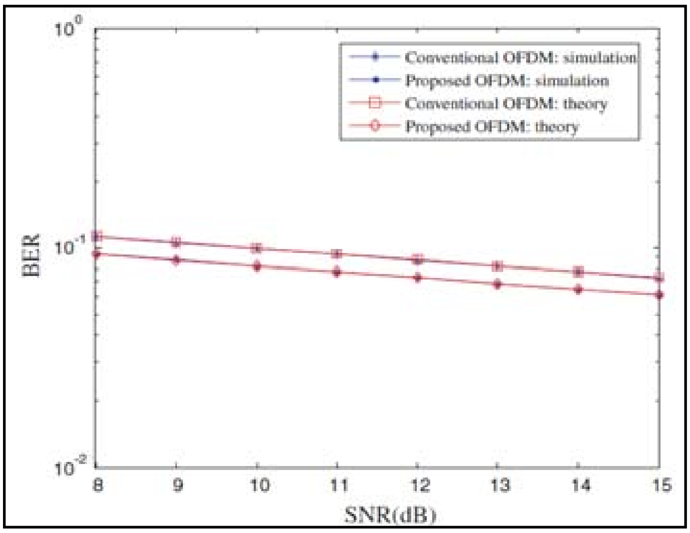

Fig. 4: Performance Comparison for OFDM Systems: Channel A

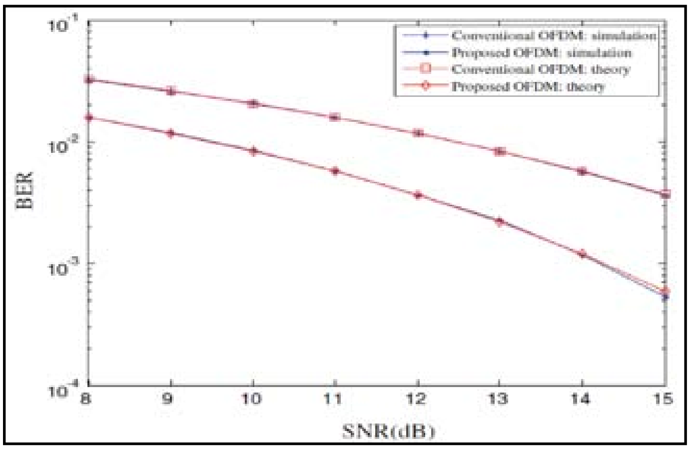

Fig. 5: Performance Comparison for OFDM Systems: Channel B

For simplicity, we assume that the maximum-likelihood (ML) estimation method is usedat the receiver, although the BER performance in theory is based on Costas loop demodulation. From figs. 4 and 5, one can clearly see the improvement of the proposed OFDM systemperformance. Since the non-spectral-null property of Channel B is better than that of ChannelA, one can see that the BER performances of all the OFDM systems in fig. 5 for Channel Bare better than the ones in fig. 4 for Channel A.

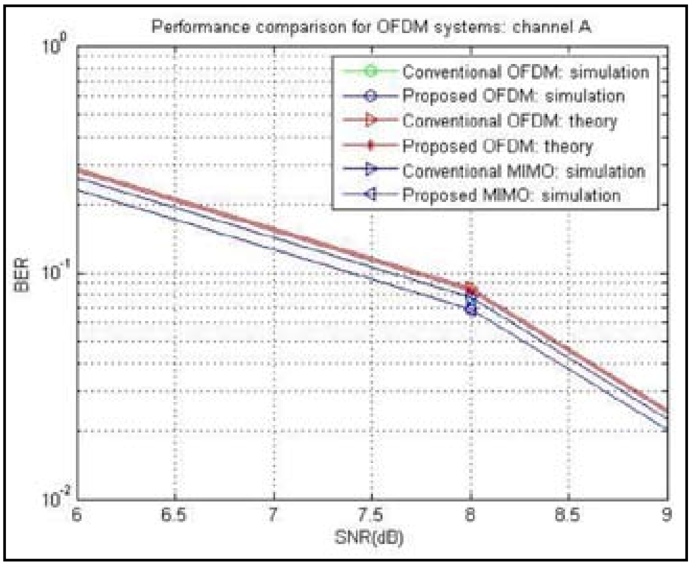

Fig. 6: Performance Comparison of Different Systems for Channel A

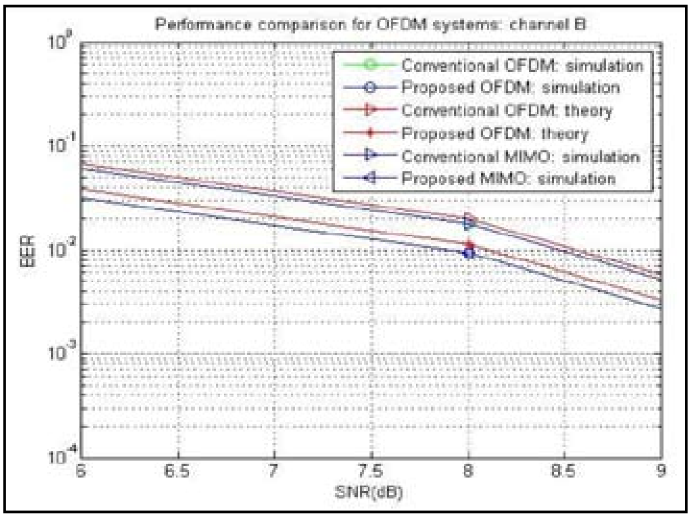

Fig. 7: Performance Comparison of Different Systems for Channel A

IV. Conclusion

In this paper, we proposed a novel Haar wavelet-based BPSKOFDM - MIMO system. Since theHaar wavelet transformation is used in our proposed OFDM system, half of the informationsymbols are zeros and the rest are either√2 or −√2 in each OFDM symbol. The simulationresults and theory analysis illustrate the proposed system has two advantages compared withconventional OFDM system: (1) reduces the PAPR by 3dB at most (2) shows robustness tospectral null channels, improving BER performance 3dB at most. Analysis also shows thatour proposed OFDM system does not increase too much computational complexity at thetransmitter. It has been shown that the MIMO concept is a goodmeans to do that.

But then another challenge faces us. The pilot patterns must beredesigned to be suitable for implementation in MIMO OFDM. We enhance theoverall system performance by implementing the MIMO concept. The channelestimation in MIMO becomes a third challenge. We solve this challenge by makingthe designed pilot patterns suitable for MIMO.

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