Slantlet Transform Based MC-CDMA Transceiver System for Wireless Communication

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Abstract: *Wireless communications is a rapidly growing piece of the communications manufacturing, with the potential to provide high-speed high-quality information exchange between the portable devices located anywhere in the world. Multi Carrier Code Division Multiple Access (MC-CDMA) has emerged recently as a promising candidate for the next generation broad-band mobile networks. Recently, it was found that Slantlet transform (SLT) based Orthogonal Frequency Division Multiplexing (OFDM) is capable to reduce the Inter Symbol Interference (ISI) and the Inter Carrier Interference (ICI), which are caused by the loss of orthogonality between the subcarriers. SLT-OFDM can support higher spectrum efficiency than Fast Fourier Transform-based OFDM (FFT-OFDM) due to the elimination of the Cyclic Prefix (CP). In this paper performance of SLT-MC-CDMA transceiver under various channel like AWGN channel and selective frequency fading channel is analyzed using two different codes like Walsh-Hadamard code and gold sequence. Proposed SLT-MC-CDMA transceiver design is based on the SLT-OFDM that is used as a basic building block in the design of MC-CDMA transceiver to maintain the orthogonality against the multipath selective frequency fading channels. Simulation results are provided to demonstrate the significant gain in the performance of the proposed technique compared to conventional MC-CDMA system*

Keywords**:** *Slantlet Transform, Slantlet based OFDM, Wavelet based MC-CDMA, Spreading codes, Spectrum Efficiency.*

1. INTRODUCTION

Next generation communication systems require high bit rate transmission to keep promise of high quality communication. The fourth generation of wireless communications known as 4G provides a high data transmission speed of around 100 megabits/second (Mbps).The best part of 4G is that the stationary users can get up to 1 gigabits/ second (Gbps), which is a remarkable development. There are many candidates for 4G, CDMA can be considered as one among them. Multi-carrier modulation (MCM) technique like OFDM can be termed as another option for 4G systems. Both the techniques have their own merits and demerits when they are employed in different communication schemes separately. But when they are employed together by combining the merits of both the systems; we obtain multi carrier-Code Division Multiple Access (MC-CDMA) [1]. Thus this combination of Multi-carrier modulation (MCM) and Code Division Multiple Access will yield better results in the communication system than being employed separately [2].

Reliability of the air interface, fading and has been the focus of most of the wireless system which was designed in the early period, whereas the concept of spectral efficiency has become the focus in recent years for the design of the wireless system .Conventional multi carrier CDMA is implemented by means of IFFT and FFT operators[3]. In its frequency spectrum, the main lobe does not concentrate energy effectively and side lobe attenuates slowly; the multipath fading or synchronization error will cause severe performance degradation due to the inter-channel interference (ICI), inter-symbol interference (ISI) and multi-access interference (MAI). Moreover, conventional multicarrier CDMA often resorts to cyclic prefix (CP) to eliminate the ISI and maintain orthogonality between neighbouring sub-carrier, which decreases the efficiency of spectrum utilization considerably in some communication scenarios. To search for an efficient multicarrier CDMA scheme, a number of improved multicarrier CDMA systems have been proposed. Among them, wavelet based multicarrier CDMA systems [4] attract some interests due to their better ability to combat ICI and ISI than conventional DFT based multicarrier CDMA (DFT-MC-CDMA) system.

In wavelet based MC-CDMA , the Fourier based complex exponential carriers of the conventional OFDM system was interchanged with some spectrally efficient orthonormal wavelets in order to reduce the level of interference. The popularity of Wavelet Transform is growing because of its ability to reduce distortion in the reconstructed signal while retaining all the significant features present in the signal. Moreover with the unique time-frequency localization feature of wavelets, SNR performance of communication systems can be improved. The wavelets are derived from multistage tree-structured Haar and Daubechies orthonormal Quadrature Mirror Filter bank. Comparing with the conventional MC CDMA, it was found that the Haar and Daubechies-based orthonormal wavelets are capable of reducing the power of ISI and ICI [2]. Moreover, since the classic notion of a guard band does not apply for discrete wavelet transform (DWT) based MC CDMA, so data rates can be enhanced over those of FFT implementations**.**

In order to further reduce the level of interference, increase the spectral efficiency, and reduce the computation complexity of FFT is replaced with Slantlet Transform (SLT) in MC-CDMA system design. Slantlet Transform is first proposed by Selesnick in 1999.Slantlet Transform is an orthogonal DWT with two zero moments and with improved time localization [3]. SLT transform found important applications in signal and image processing; it has been successfully applied in image compression and denoising. It also retains the basic characteristic of the usual filter-bank such as octave band characteristic, a scale dilation factor of two and efficient implementation. In this paper, SLT is used as a main building block in design to improve the spectral efficiency of an OFDM system. However, the SLT is based on the principle of filters for different scales unlike iterated filter bank approaches for the DWT. It uses a special case of basis, the construction of which relies on Gram–Schmidt orthogonalization. Selesnick described the basis from a filter-bank viewpoint, gave explicit solutions for the filter coefficients, and described an efficient algorithm for the transform.

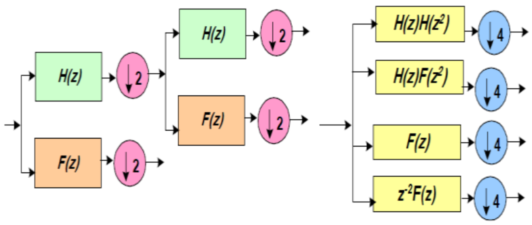
The rest of the paper is organized as follows. Section II explains Slantlet transform. Slantlet based OFDM system explained in section III. Section IV gives description of proposed system model. Section V consists of the simulation results and observations for the comparison between proposed system and conventional system in different channel conditions. The conclusion of the study is given in Section VI.

2. SLANTLET TRANSFORM

The Discrete Wavelet transform (DWT) is usually carried out by filter bank iteration, but for a fixed number of zero moments it does not yield a discrete time basis that is optimal with respect to time localization. The Slantlet transform (SLT) is an orthogonal DWT with 2 zero moments and with improved time localization. It is a recently developed multi resolution technique especially well-suited for piecewise linear data. This technique is introduced by Selesnick in 1999[6].The Slantlet transform has been developed by employing the lengths of the discrete time basis function and their moments as the vehicle in such a way that both time localization and smoothness properties are achieved. Using Slantlet transform it is possible to design filters of shorter length while satisfying orthogonality and zero moments condition. The basis function retains the octave band characteristic. SLT transform found important applications in signal and image processing; it has been successfully applied in image compression and de noising. It also retains the basic characteristic of the usual filter-bank such as octave band characteristic, a scale dilation factor of two and efficient implementation. However, the SLT is based on the principle of designing different filters for different scales unlike iterated filter-bank approaches for the DWT [4]. In this paper, SLT found a new application; it is used as a main building block in designing an improving the spectral efficiency of an OFDM system where the SLT modulator replaces the FFT modulator.

It uses a special case of a class of bases described by Alpert in [7], the construction of which relies on Gram–Schmidt orthogonalization. SLT is based on the principle of designing different filters for different scales unlike iterated filter-bank approaches for the DWT. Selesnick described the basis from a filter-bank viewpoint, gave explicit solutions for the filter coefficients, and described an efficient algorithm for the transform.

The usual iterated DWT filter-bank and its equivalent1 form are shown in Fig.1. The “slantlet” filter-bank is based on the equivalent structure that is occupied by different filters that are not products. With this extra degree of freedom obtained by giving up the product form, filters of shorter length are designed satisfying orthogonality and zero moment conditions.



(a) Two-scale iterated filter-bank DWT **(b)** Equivalent form using

Fig. 1. Two-scale iterated filter-bank and its equivalent form using the DWT

For two-channel case the Daubechies filter [6] is the shortest filter which makes the filter-bank orthogonal and has *K* zero moments. For *K=2* zero moments, filters *H(z)* and *F(z)* are of length 4. For this system, the iterated filters in Fig. 1 are of length 10 and 4. Without the constraint that the filters are products, an orthogonal filter-bank with *K=2* zero moments can be obtained where the filter lengths are 8 and 4. That is a reduction by two samples, which is a difference that grows with the number of stages. This reduction in length, while maintaining desirable orthogonality and moment properties, is possible because these filters are piecewise linear. Even though there is no tree structure for SLT, it can be efficiently implemented like an iterated DWT filter-bank [6]. Therefore, a computational complexity of the SLT is of the same order as that of the DWT.

3. SPREAD SPECTRUM

Spreading the transmitted signal bandwidth will provide with lots of benefits. Spreading of spectrum signal over a wider bandwidth will allow its coexistence with that of narrow-band signals. Also there would be only a very slight increase in the noise floor for that of a given spectrum. The spread spectrum modulation can be classified into two major forms namely Direct Sequence and Frequency Hopping.

Being one of the popular spread spectrum, Direct Sequence can be implemented with greater simplicity. A high speed pseudo-noise code sequence is created by pseudo-random noise generator in this form of modulation. Thus the generated sequence is transmitted at the a maximum bit rate called the chip rate. The transmitted radio frequency (RF) bandwidth is directly set by modulating the narrow-band carrier using pseudo-random code. The spread of the information is direly linked to that of chip rate. By multiplying the signal with a locally generated version of the pseudo-random code sequence the information is demodulated. There are various other methods in addition to direct sequence which uses different approaches to spreading for implementing spread spectrum.

Whenever the concept of spreading takes place by hopping from frequency to frequency over a wide band it is termed as Frequency Hopping. A hopping table generated with the use of a pseudo-random code sequence determines the specific order in which the hopping occurs. The rate of hopping can be given as the function of the information rate.

The usage of that of spread spectrum will provide a lot of advantages. Sharing the same frequency band with other users is possible as spread-spectrum receivers can effectively ignore narrow-band transmissions. It may be learnt from the discussed techniques that a pseudo-random noise sequence was used to directly modulate the signal in the first case or it was used to determine the order of frequencies in the hopping table is the latter case. Only those receivers possessing the proper duplicate pseudo-random noise code sequence will be able to recover the signal as pseudo-random signal makes the transmitted signal appear as noise. Thus it would provide a great deal of privacy in the case of point-to-point communications. The fact that the noise-like character of the transmitted signal drastically reduces the probability of signal detection and interception to ensure secure communications. As strong encryption and spoofing countermeasures could be added at great cost to existing narrow-band communications, it would make the concept of secure communications using other techniques not of much importance. But it is important to note that by using that of the spread spectrum transmission, point-to-point communications can be possible without much coordination of the speaker.

3.1 Walsh-Hadamard Code

It is a decodable code which recovers parts of the original message with high probability, while only looking at a small fraction of the received word Orthogonality is the most important property of Walsh–Hadamard codes which provides the zero cross-correlation between any two Walsh–Hadamard codes of the same set when the system is synchronized. It is a linear code over a binary alphabet that maps messages of length n to codeword of length 2n. Each non-zero codeword has Hamming weight of exactly 2n − 1, which implies that the distance of the code is also 2n − 1. In standard coding theory notation, this means that the Walsh–Hadamard code is a [2n, n, 2n / 2]2-code. The generating algorithm is as follows.

$$H_{2N} = \begin{bmatrix} H_N & H_N \\ H_N & \overline{H_N} \end{bmatrix} \quad (1)$$

where N is a power of 2 and N can be defined from the following recurrent rule :

$$H_0 = [1] \quad (2)$$

$$H_1 = \begin{bmatrix} H_0 & H_0 \\ H_0 & -H_0 \end{bmatrix} \quad (3)$$

$$H_{i+1} = \begin{bmatrix} H_i & H_i \\ H_i & -H_i \end{bmatrix};\ \text{i=1}\ldots log_2(N) - 1; \quad (4)$$

3.2 *Gold Sequence*

Gold sequences, which belong to the family of PN sequences can be said as the one which is popular for non-orthogonal CDMA systems. As the length of the code increases, Gold sequences which will have only three cross-correlation peaks will incline to get less important. A modulo-2 addition of two maximum length sequences are employed to construct the Gold codes by synchronous clocking, the code sequences are added chip by chip. Because the m-sequences are of the same length, the two code generators maintain the same phase relationship, and the codes generated are of the same length as the two base codes, which are added together, but non-maximal. A new sequence is generated for every change in phase position between two generated m- sequences. the autocorrelation and cross-correlation between the codes is uniform and bounded in the case of Gold sequences which makes it preferable choice to other set of codes available. The generated Gold sequences have a three-valued cross- correlation when specially selected m-sequences, called preferred m-sequences, are used. multiple access on the channel and also asynchronous transmission are permitted in Gold sequences. We can generate 2n - 1 Gold sequences by using two m-sequences. The autocorrelation property of the Gold sequence allows the receiver to synchronize.

4. SLANTLET BASED OFDM SYSTEM

The block diagram of the SLT-OFDM system is depicted in Fig. 2 It is very similar to the FFT-OFDM with some differences in the OFDM modulator-demodulator blocks. The processes of serial to parallel (S/P) conversion, signal de-mapping, and training sequence insertion are the same. The SLT-based OFDM modulator consists of zero

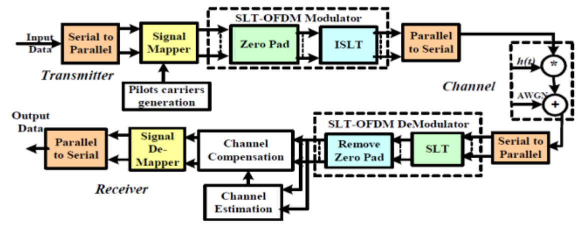


Fig. 2 Block Diagram of SLT-OFDM System

padding and Inverse SLT (ISLT) blocks while the SLT-based OFDM demodulator consists of SLT and zero-pad removal blocks. The main difference between FFT-OFDM and SLT-OFDM is that in SLT-OFDM there is no need for adding a CP to OFDM symbols; therefore the spectral efficiency and the data rate of SLT-OFDM are better than those of FFT-OFDM.

5. *SLANTLET TRANSFORM BASED MC-CDMA (SLT-MC-CDMA) SYSTEM*

In this section a novel SLT-MC-CDMA transceiver system is presented based on the SLT-OFDM that is used as a basic building block in the design of MC-CDMA transceiver system. Implementation of the proposed system is done by using MATLAB software. The MC-CDMA transmitter spreads the original data stream over different sub-carriers using a given spreading code in the frequency domain [8]. Fig. 3 shows the M1C-CDMA transmitter of the k^{th} user for BPSK scheme, where d_k(t) is the data bits for k^{th} user, G_{MC} denotes the processing gain, N_C is the number of sub-carriers and $C_k(t)$ is the spreading Pseudo-random Noise (PN) sequence of the k^{th} user. It is assumed that $N_C = G_{MC}$ [8].

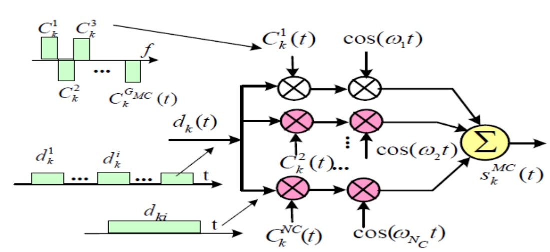


Fig. 3 MC-CDMA transmitter system model

In MC-CDMA systems, the original data stream from a user is spread with the user's specific spreading code in the frequency domain. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. The narrowband subcarriers are generated using BPSK modulated signals, each at different frequencies, which at baseband are multiples of harmonic frequency $1/T_S$ given in equation 5.

$$\Delta f = f_i - f_{i-1} = \frac{1}{T_s} \quad (5)$$

Where, T_S is the symbol duration of data stream. The subcarrier frequencies are orthogonal to each other at baseband. The transmitted signal of the k^{th} user is given by equation 6.

$$S_k^{MC}(t) = d_k(t) \sum_{i=1}^{N_C} C_k^i \cos(\omega_i t) \quad (6)$$

The total bandwidth required for transmission is given in equation 7

$$\beta = \frac{(N_C+1)G_{MC}}{N_C T_S} \quad (7)$$

The received signal of MC-CDMA systems for all K users as fig. 4 shows is given by equation 8.

$$r(t) = \sum_{k=1}^{K} d_k(t) \sum_{i=1}^{N_C} h(i)\, C_k^i \cos\omega_i t + n(t) \quad (8)$$

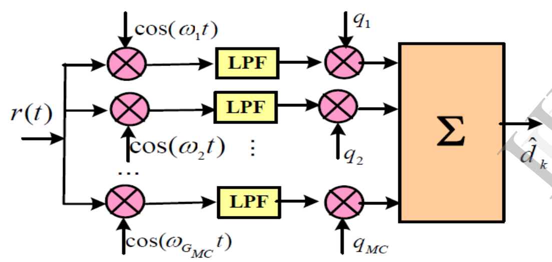


Fig. 4 MC-CDMA receiver system model

Where n(t) is the Additive White Gaussian Noise (AWGN) and h(i) is the complex signal channel coefficient of the i^{th} subcarrier. The received signal is demodulated with corresponding subcarrier followed by low pass filtering to generate the baseband signal. The baseband signal is weighted by some coefficients, and then all baseband signals are combined together. It can be seen that the received signal is combined in the frequency domain therefore the receiver can always employ all the received signal energy scattered in the frequency domain. This is the advantage of MC-CDMA [8].

The block diagram of the proposed system for SLT based MC-CDMA is depicted in Fig. 5. In this design the FFT-Based OFDM is replaced with a SLT-based OFDM which has a better performance and a reduced ISI and ICI in comparison with FFT-based OFDM. Each data symbol is multiplied with a spreading sequence, Walsh-Hadamard (WH) code or Gold sequence can be used since both of them have good correlation values.

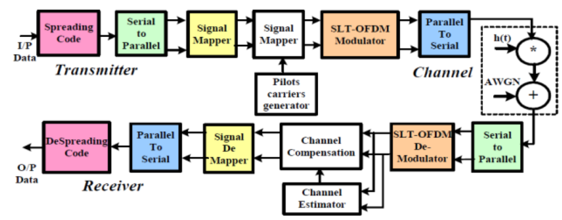


Fig. 5 Block Diagram of proposed SLT-MC-CDMA System

Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK) signal mapping can be used for mapping the spreading and the training sequences. After that a pilot carrier (training sequence) which may be a bipolar sequence previously informed to receiver is generated. The channel frequency response is estimated by using the training and the received sequences as in equation 9.The channel frequency response previously found is used to compensate the channel effects on the data.

$$H(k) = \frac{Received\ training\ sample\ (k)}{Transmitted\ training\ sample\ (k)} \quad (9)$$

6. SIMULATION RESULTS

In this section the results of BER performance simulations using MATLAB 7 for SLT-MC-CDMA are provided and compared with the conventional FFT-MC-CDMA under different channel conditions. AWGN channel, Flat Fading Channel (FFC), and multi-path frequency selective Rayleigh distributed with AWGN channel (SFC) are considered during simulations. The effect of using different spreading codes in the SLT-MC-CDMA system under AWGN channel is also investigated. The simulated results are given below.

6.1 BER Performance of SLT-MC-CDMA using Walsh-Hadamard code in AWGN Channel

The Bit Error Rate performance of the proposed SLT-MC-CDMA and the conventional FFT-MC-CDMA system in an AWGN channel using Walsh-Hadamard code is shown in Fig. 6. Walsh-Hadamard matrix of order 64 is used as the spreading code in this simulation. The SNR is changed from 0dB to 25dB, from which it can be noted that the SLT-MC-CDMA has an SNR gain of 15dB compared with the FFT-MC-CDMA system to achieve a BER of 10^{-2}.

Also it has an SNR gain of 16dB compared with FFT-MC-CDMA system to achieve a BER of 10^{-3}.

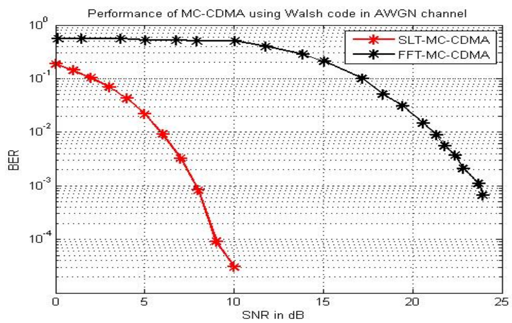


Fig .6 BER Performance of MC-CDMA using Walsh-Hadamard code in AWGN channel

6.2 BER Performance of SLT-MC-CDMA using Gold sequence in AWGN Channel

The BER performance of the proposed SLT-MC-CDMA and the conventional FFT-MC-CDMA system in AWGN channel using Gold sequence is shown in Fig.7.Here also SNR is changing from 0dB to 25dB. From figure, SLT-MC-CDMA has an SNR gain of 16dB compared with FFT-MC-CDMA system to achieve BER of 10^{-2}. Also it has an SNR gain of 16dB compared with FFT-MC-CDMA system to achieve BER of 10^{-3}.By comparing with Walsh-Hadamard coded MC-CDMA, Gold coded MC-CDMA also getting similar results. Since both codes show good correlation values, when small number of users are present in the proposed system.

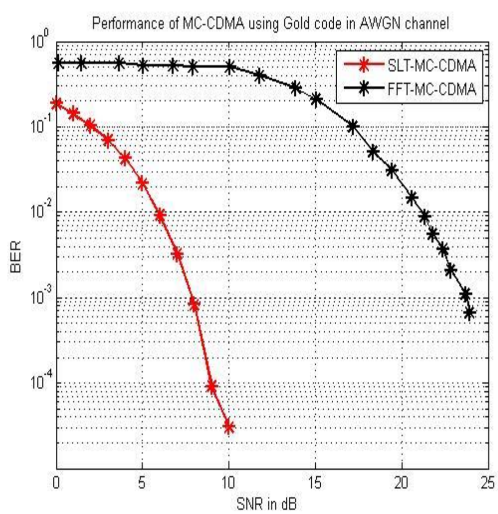


Fig 7 BER Performance of MC-CDMA using Gold sequence in AWGN channel

6.3 BER performance of SLT-MC-CDMA in SFC with maximum path delay=2 sample using Walsh-Hadamard code

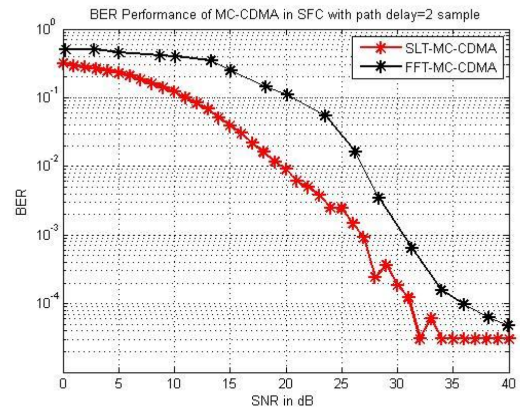


Fig.8 BER performance of SLT-MC-CDMA using Walsh-Hadamard code in SFC with maximum path delay=2 sample

Simulation result of Walsh Hadamard code based SLT-MC-CDMA in selective fading channel with path gain equal -5dB, Doppler shift equals 5Hz and path delay equal 2 sample is shown in Fig.8. It is seen that SLT-MC-CDMA is always better than that of FFT-MC-CDMA system. SLT-MC-CDMA has $BER = 10^{-3}$ at SNR = 26dB, while FFT-MC-CDMA system has $BER = 10^{-3}$ at SNR =30dB.

6.4 BER performance of SLT-MC-CDMA in SFC with maximum path delay=2 sample using Gold sequence

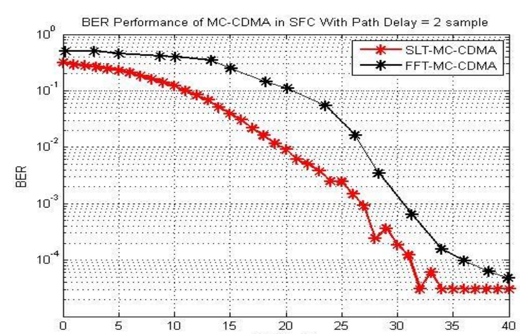


Fig.9 BER performance of SLT-MC-CDMA using Gold sequence in SFC with maximum path delay=2 sample

Fig 9 shows BER performance simulation of Gold sequence based SLT-MC-CDMA in selective fading channel with path gain equal -5dB, Doppler shift equals 5Hz and path delay equal 2 sample with Doppler shift 5Hz. Figure shows that SLT-MC-CDMA has BER= 10^{-3} at SNR in dB =26, while FFT-MC-CDMA system has BER= 10^{-3} at about 30dB.

7. CONCLUSIONS AND FUTURE WORK

An MC-CDMA system is designed and implemented; SLT-OFDM transceiver scheme is used in proposed MC-CDMA system instead of conventional FFT-OFDM. A robust to noise interference SLT is used to improve the performance of the communication system without a need to use the cyclic prefix. Comparing the performance of SLT-MC-CDMA and FFT-MC-CDMA in AWGN channel, FFC and SFC indicated that for AWGN channel SLT-MC-CDMA has performance gain about 16dB compared with FFT-MCCDMA to achieve BER=10^{-3}. For FFC and for different maximum Doppler shift, SLT-MC-CDMA system has better performance than conventional system, it has performance gain of about 21dB compared with FFT MC-CDMA to achieve BER =10^{-2}. Maximum Doppler shift badly affects the performance of SLT-MC-CDMA compared with other channel parameters. It can be noted that CDMA when combined with OFDM, has BER performance better than just using OFDM only. Simulation results show that proposed SLT design achieves much lower Bit Error Rates (BER), increases Signal to Noise power Ratio (SNR), and can be used as an alternative to the conventional MC-CDMA. Both Walsh-Hadamard codes and Gold sequence codes were used as spreading codes in the implementation and analysis of SLT-MC-CDMA system in AWGN channel and selective frequency fading channel. When the number of users considered was small, both codes show similar performance.

There can be lot of growth in this field in the future. Incorporation of coding techniques in the proposed system will improve the system and enhance the BER performance.

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