LOW DENSITY PARITY CHECK (LDPC) CODES FOR A PROPOSED SLANTLET TRANSFORM OFDM SYSTEM IN A RAYLEIGH FADING CHANNELS WITH PERFECT AND PILOT CHANNEL ESTIMATION FOR M_ARY PSK MODULATION[1]

Lect. Ghanim Abd Al-Kareem[2]

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a very attractive technique for high bit rate data transmission in a multipath fading environment that causes intersymbol interference (ISI). In this paper, two steps are used to improve the error rate performance of OFDM system. First, we proposed the Slantlet Transform (SLT) used instead of Fast Fourier Transform (FFT) to obtain high orthogonality properties between subcarriers and hence reduce (ISI). Second, we proposed the Low Density Parity Check (LDPC) Codes for the proposed SLT-OFDM system to improve the Bit Error Rate (BER) and Packet Error Rate(PER) performance.

The goal of the proposed SLT method is to reduce the energy needed to transmit data on a fading channel and to decrease the number of complex computations(addition and multiplication) and hence increase the speed of the system in addition to obtaining high orthogonality between subcarriers. Hence, the proposed LDPC-based SLT-OFDM system is a promising solution to high efficient data transmission over fading channels. The proposed system has been tested and validated using MATLAB 7 package.

Keywords: Low-Density Parity-Check Codes, Orthogonal Frequency Division Multiplexing , Slantlet Transform , Rayleigh Fading Channels, Channel Estimation

الخلاصة

التعدد ألتقسيمي الترددي المتعامد(OFDM) هي تقنية فعالة جدا لزيادة معدل نقل البيانات في قنوات الخفوت متعددة المسارات والتي تسبب التداخل بين الرموز(ISI). في هذا البحث تم عمل مقترحين من اجل تحسين أداء معدل الخطأ في نظام OFDM : أولا ،اقتراح استخدام تحويل Slantlet بدلا من تحويل فوريرالسريع (FFT) للحصول على خصائص تعامدية عالية بين الحوامل الجزئية وبالتالي تخفيض التدخل بين الرموز ، والثانية : اقترحنا استخدام الرموز ذات مصفوفة فحص التماثل منخفضة الكثافة LDPC مع النظام المقترح الاول SLT-OFDM لتحسين معدل خطأ البت BER ومعدل خطأ الرزمة PER.

ان الهدف من مقترح تحويل SLT هو لتخفض الطاقة اللازمة لنقل البيانات في قنوات الخفوت و تقليل عدد العمليات الحسابية المعقدة (الجمع والضرب) ، وبالتالي زيادة سرعة النظام إضافة الى الحصول على التعامدية العالية بين الحوامل الجزئية. وبالتالي ، فإن المقترح LDPC المستندة إلى النظام المقترح SLT-OFDM هو حل واعد لكفاءة عالية لنقل البيانات عبر قنوات الخفوت. لقد تم اختبار النظام المقترح باستخدام MATLAB 7 package.

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[2] Electrical Engineering Department - College of Engineering - Al-Mustansiriya University.

1-Introduction

The basic principle of OFDM is to split a high rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of sub-carriers. Because the lower rate parallel subcarriers increase the symbol duration so the relative amount of dispersion in time caused by multi-path delay spread is decreased. Inter symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. The guard time is chosen larger than the expected delay spread so that the multipath components forming one symbol cannot interfere with the next symbol. However, the problem of Inter Carrier Interference ICI would arise. ICI is a crosstalk between different sub carriers, which means that they are no longer orthogonal (orthogonality is lost). Hence, to eliminate ICI, the OFDM symbol is cyclically extended in the guard time, which is done by taking symbol period samples from the end of OFDM symbol and appending them to the start of OFDM symbol. This ensures that the OFDM symbol always has integer number of cycles within the FFT interval, as long as the delay is smaller than the guard time. As a result, the multipath signals with delays smaller than the guard time cannot cause ICI. In this case, the total length of the symbol is [1-5].

$$Tf = TG + TFFT \quad \ldots(1)$$

Where Tf is the total length of the symbol in samples, TG is the length of the guard period in samples, and TFFT is the size of the IFFT used to generate the OFDM signal and usually TG is smaller than (symbol time / 4) [1-5].

2-Channel Estimation

In this paper, the method used to compensate phase error due to fading is a pilot symbol–aided OFDM modulation scheme which is the most sensible for channel estimation especially when the channel is time variant. In this method pilot symbols are inserted at the transmitter at fixed time intervals and at the receiver. The channel characteristics are estimated by using the pilot symbol because the level of fluctuation is independent in each sub carrier channel. The pilot carried in all frequency domains can be inserted at a known time period.Then, by using the estimated channel characteristics, the transmitted data can be recovered. The pilot data are inserted only in the in phase channel. The relation between the transmitted pilot data (ice0, qce0) and the received pilot data (ice1, qce1) are given By[6].

$$\begin{pmatrix} ice1 \\ qce1 \end{pmatrix} = A \begin{pmatrix} ice0 \\ qce0 \end{pmatrix} \quad \ldots(2)$$

where A is the transition matrix of the fading environment

$$A = \begin{pmatrix} iv & -qv \\ qv & iv \end{pmatrix} \quad \ldots(3)$$

To compensate the phase error all the received data are multiplied by the complex conjugate of A

$$A^{-1} = \frac{1}{\sqrt{iv^2 + qv^2}} \begin{pmatrix} iv & qv \\ -qv & iv \end{pmatrix} \quad \ldots(4)$$

The values of iv and qv are given by

$$iv = \frac{1}{\sqrt{ice1 + qce1}} (ice0 * ice1 + qce0 * qce1) \quad \ldots(5)$$

$$qv = \frac{1}{\sqrt{ice1 + qce1}} (qce0 * ice1 - ice0 * qce1) \quad \ldots(6)$$

3- Slantlet Transform (SLT)

The Slantlet Transform (SLT) is an orthogonal Discrete Wavelet Transform (DWT) with two zero moments, improved time localization, and is based on designing different filters that are not a product for each scale instead of using filterbank iteration. In general, the algorithm to obtain the L-scale Slantlet filterbanks is, as follows[5,7]:

1- The L -scale Slantlet has 2L filterbanks. The first filterbank is called the low pass filter (LPF), and its transfer function is $h_L(n)$. The one adjacent to the LPF filterbank has transfer function $f_L(n)$. Both $h_L(n)$ and $f_L(n)$ are to be followed by down sampling of 2L.

2- The remaining 2L -2 filterbanks, their transfer functions are gi(n) and its shifted time reverse gi((2i+1-1)-n) for i= L -1, L -2,…,1. Each gi(n) and its shifted time reverse are to be followed by down sampling of 2i+1 for each value i.

The Slantlet filterbank appears each gi(n) with its time reverse gi((2i+1-1)-n), while $h_L(n)$ does not appear with its time reverse, It always appears paired with the filter $f_L(n)$. The transfer functions $h_L(n)$, $f_L(n)$ and gi(n) for L-scale Slantlet are calculated using the following expressions[7] and the parameters are shown in Tables (1) and (2) respectively.

$$h_i(n)=\begin{cases} b_{0,0}+b_{0,1}n & for\ n=0,...,2^i-1 \\ b_{1,0}+b_{1,1}(n-2^i) & for\ n=2^i,...,2^{i+1}-1 \end{cases} \quad ...(7)$$

$$f_i(n)=\begin{cases} c_{0,0}+c_{0,1}n & for\ n=0,...,2^i-1 \\ c_{1,0}+c_{1,1}(n-2^i) & for\ n=2^i,...,2^{i+1}-1 \end{cases} \quad ...(8)$$

$$g_i(n)=\begin{cases} a_{0,0}+a_{0,1}n & for\ n=0,...,2^i-1 \\ a_{1,0}+a_{1,1}(n-2^i) & for\ n=2^i,...,2^{i+1}-1 \end{cases} \quad ...(9)$$

Table (1): $h_L(n)$ and $f_L(n)$ parameters
$m = 2^i$
$u = 1/\sqrt{m}$
$v = \sqrt{(2m^2+1)/3}$
$b_{0,0} = u(v+1)/(2m)$
$b_{1,0} = u - b_{0,0}$
$b_{0,1} = u/m$
$b_{1,1} = -b_{0,1}$
$q = \sqrt{3/(m(m^2-1))}/m$
$c_{0,1} = q(v-m)$
$c_{1,1} = -q(v+m)$
$c_{1,0} = c_{1,1}(v+1-2m)/2$
$c_{0,0} = c_{0,1}(v+1)/2$

Table (2): gi(n) parameters
$m = 2^i$
$s_1 = 6\sqrt{m/((m^2-1)(4m^2-1))}$
$t_1 = 2\sqrt{3/(m(m^2-1))}$
$s_0 = -s_1(m-1)/2$
$t_0 = ((m+1)s_1/3 - mt_1)(m-1)/(2m)$
$a_{0,0} = (s_0+t_0)/2$
$a_{1,0} = (s_0-t_0)/2$
$a_{0,1} = (s_1+t_1)/2$
$a_{1,1} = (s_1-t_1)/2$

4-Proposed Slantlet Transform For OFDM system

Many researches appeared recently to improve the performance of OFDM systems. The way is done by replacing the FFT transform by any other transforms such as Discrete Wavelet Transform (DWT) and Discrete Multiwavelet Transform (DMWT).

In this paper, first the Slantlet Transform (SLT) is proposed to be used instead of Fast Fourier Transform (FFT) in the

OFDM modulator and demodulator to obtain better performance for OFDM system. The filters in the SLT depends on the wavelet function, namely Daubechies basis functions where these functions are simple designed with respect to sine and cosine functions of FFT and IFFT. The SLT is better than DWT because the length of the filters will be reduced, and that leads to reducing the number of computations which lead to increasing the speed of operations in the system[7].

Figure (1) show the block diagram of the proposed SLT-OFDM system. In the transmitter, the Inverse Slantlet Transform (ISLT) is used instead of Inverse Fast Fourier Transform (IFFT) to modulate a block of input modulated values onto a number of sub-carriers and in the receiver, the sub-carriers are modulated by Slantlet Transform (SLT) instead of Fast Fourier Transform (FFT), which performs a reverse operation of an ISLT.

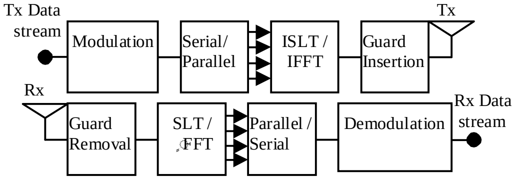


Figure (1) Proposed SLT-OFDM system (transmitter & receiver)

In the future the high-bit rate transmission is required for high quality mobile communication systems. Orthogonal Frequency Division Multiplexing (OFDM), is a very attractive technique for the high-bit-rate data transmission in a multipath environment that causes intersymbol interference (ISI). The ISI in OFDM can be eliminated by adding a guard interval. In a multipath environment, some subcarriers of OFDM may be completely lost because of the deep fades. Hence, even though most subcarriers may be detected without errors, the overall bit error rate (BER) will be largely dominated by a few subcarriers with small amplitudes. To avoid this domination by the weakest subcarriers, forward-error correction coding is essential. Many error correcting codes have been applied to OFDM, Convolutional codes, Reed Solomon code and Turbo code[8].In this paper, Low Density Parity Check (LDPC) Code is suggested for the proposed SLT-OFDM system.

5-Low Density Parity Check (LDPC) Code

LDPC codes and their iterative decoding algorithm proposed by Gallager in 1962 have excellent properties. The, LDPC codes are now recognized as good error correcting codes achieving near Shannon limit performance[9].The name of the LDPC codes comes from the characteristics of their parity-check matrix which contains only a few 1's in comparison to the amount of 0's[10].

LDPC codes are defined as codes use a sparse parity-check matrix with the number of l's per column (column weight) and the number of l's per row (row weight), both of which are very small compared to the block length. LDPC codes are classified into two groups, regular and irregular LDPC codes. Regular LDPC codes have a uniform column weight and row weight, and irregular LDPC codes have a nonuniform column weight. (N,K) LDPC code is defined by M x N parity-check matrix H, where K = N - M and the code rate is R = K/N. If the H doesn't have full rank, K > N - M the error performance of an LDPC code becomes worse. Thus, when we construct the parity-check matrix H, we will ensure that all the rows of the matrix are linearly independent[8,9,11].

LDPC codes can be represented by a Factor Graph or Tanner Graph that contains two types of nodes: the "bit nodes" and the "check nodes". Figure 2(a) shows an example of the Factor Graph. Each bit node corresponds to a column of a parity-check matrix, which also corresponds to a bit in the codeword. Each check node corresponds to a row of a parity-check matrix, which represents a parity-check equation. An edge between a bit node and a check node exists if and only if the bit participates in the parity-check equation represented by the check node[8,9,11]. LDPC codes can be decoded by using a probability propagation algorithm known as the sum product or belief propagation algorithm, which is implemented by using a Factor graph. LDPC codes have better block error performance than turbo codes, because the minimum distance of an LDPC code increases proportional to the code length with a high probability. Such a property is desirable for the high-bit-rate transmission that requires very low frame error probability[8,11,12].

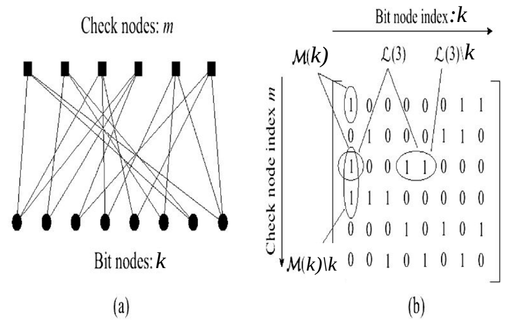


Figure 2 (a) Factor graph and (b) notation of the sum-product algorithm

5-1- Sum Product Algorithm

The notations of the sum-product algorithm is described in Figure 2 (b). FOR M(k) denotes the set of check nodes that are connected to the bit node k, i.e., positions of "1"s in the kth column of the parity-check matrix. L(m) denotes the set of bits that participates in the mth parity-check equation, i.e., the positions of "1"s in the mth row of the parity-check matrix. $q^0_{k\to m}$ *and* $q^1_{k\to m}$ denote the probability information that the bit node k sends to the check node m, indicating P(x_k=0) and P(x_k=1) respectively. $r^0_{m\to k}$ *and* $r^1_{m\to k}$ denote the probability information that the mth check node gathers for the lth bit being 0 and 1, respectively. The postcriori probability for a bit is calculated by gathering all the extrinsic information from the check nodes that connect to it, which can be obtained by the following iterative belief propagation procedure[11,13].

For binary codes, the sum-product algorithm can be performed more efficiently in Log domain, where the probabilities are equivalently characterized by the log-likelihood ratios (LLRs):

$$\begin{gathered} L(r_{m\to k}) \equiv \log(r^1_{m\to k}/r^0_{m\to k}), L(q_{m\to k}) \equiv \\ \log(q^1_{m\to k}/q^0_{m\to k}), L(p_k) \equiv \log(p^1_k/p^0_k), \\ L(q_k) \equiv \log(q^1_k/q^0_k) \qquad ...(10) \end{gathered}$$

Initialization

Each bit node k is assigned an priori LLR L(p_k). In the case of equiprobable inputs on a memoryless AWGN channel with BPSK,

$$L(p_k) = \log\frac{P(y_k \mid x_k \approx +1)}{P(y_k \mid x_k \approx -1)} = \frac{2}{\sigma^2} y_k ...(11)$$

where x,y represent the transmitted bit and received bit, respectively, and σ^2 is the noise variance. For every position (m,k) such that H_{mk} = 1, where H_{mk} represents the element of the mth row and the kth column in the parity-check matrix H, $L(q_{k\to m})$ *and* $L(r_{m\to k})$ are initialized as:

$$L(q_{k\to m}) = L(p_k) \ \ and \ \ L(r_{m\to k}) = 0 ...(12)$$

1-Checks To Bits

Each check node m gathers all the incoming information $L(q_{k\to m})$'s, and updates the belief on the bit k based on the information from all other bits connected to the check node m.

$$L(r_{m\to k}) = 2\tanh^{-1}\left(\prod_{k'\in L(m)\backslash k} \tanh(L(q_{k'\to m})/2)\right) \text{...(13)}$$

2-Bits to Checks

Each bit node k propagates its probability to all the check nodes that connect to it.

$$L(q_{k\to m}) = L(p_{kl}) + \sum_{m'\in M(k)\backslash m} L(r_{m'\to k}) \quad \text{...(14)}$$

3-Check Stop Criterion

The decoder obtains the total a posteriori probability for the bit l by summing the information from all the check nodes that connect to the bit 1.

$$L(q_l) = L(p_l) + \sum_{m\in M(l)} L(r_{m\to l}) \qquad \text{...(15)}$$

Hard decision is made on the $L(q_k)$, and the resulting decoded input $\hat{x}$ is checked against the parity-check matrix H. If $H\hat{x} = 0$, the decoder stops and outputs $\hat{x}$. Otherwise, it repeats the steps (1-3). The sum-product algorithm sets the maximum number of iterations. If the number of iterations reaches the maximum, the decoder stops and outputs $\hat{x}$ as the result of the hard decision [11, 13].

6- System Description of LDPC Coded For The Proposed SLT-OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a very attractive technique to achieve the high bit rate data transmission required for the future mobile communications. A major drawback of OFDM is its high peak to average power ratio (PAPR). Many researches have been done to reduce the PAPR. In a multipath fading channel, some subcarriers of OFDM may be completely lost because of the deep fades. Hence, even though most subcarriers may be detected without errors, the overall bit error rate (BER) will be largely dominated by a few subcarriers with the smallest amplitudes[11].To improve the error rate performance of proposed SLT-OFDM, forward error correction coding is essential. Recently, low density parity check (LDPC) codes, which can achieve the near Shannon limit performance, attracted much attention. We proposed the LDPC coded for proposed SLT-OFDM (LDPC-SLT-OFDM)systems to improve the error rate performance of proposed SLT-OFDM system on a Rayleigh fading channel. In mobile communications the high bandwidth efficiency is required, and thus the multilevel modulation is preferred. LDPC codes have been applied to Mary PSK modulation on additive white Gaussian noise (AWGN) channel and a Rayleigh fading channels.

Figure (3) shows the modified model of the proposed LDPC-SLT-OFDM system. At the transmitter, information bits are encoded at the LDPC encoder and modulated at the Mary PSK modulator. After the serial-to parallel conversion, the OFDM sub-channel modulation is implemented by using an inverse slantlet transform (ISLT) and assigned to some OFDM symbols for the purpose of compensating two dimensional errors in the OFDM system. On a fading channel the guard interval is inserted for the purpose of eliminating the ISI. At the receiver, the guard interval is removed on a fading channel. After the serial-to-parallel conversion, the OFDM subchannel demodulation is implemented by using a slantlet transform (SLT). The received OFDM symbols generated by the SLT are demodulated at the Mary PSK demodulator. The demodulated bits are decoded with each LDPC encoded block and data bits are restored.

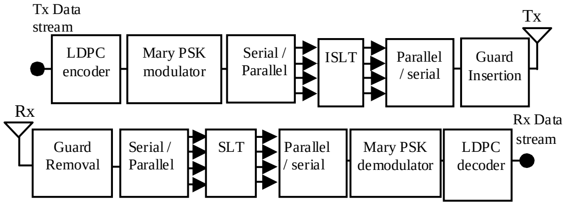


Figure (3) Proposed LDPC-SLT-OFDM system model(transmitter & receiver)

<u>7- Performance By Computer Simulation</u>

<u>7-1 Performance Of The Proposed SLT-OFDM System In AWGN Channel</u>

All the implementation concepts have been verified in MATLAB Version 7 and the evaluation of the proposal SLT-OFDM system is presented and compared with traditional FFT-OFDM system with Mary PSK modulation using the Gray mapping. The measurement for the performance is displayed as Bit Error Rate (BER) and Packet Error Rate (PER) in comparison to signal to noise ratio (SNR) of the AWGN channel or a Rayleigh fading channel. The block diagram of the computer simulation for the proposed SLT-OFDM modulator and demodulator are shown in Figure (1) .The standard parameters used in our simulations which are affect the performance of the proposal SLT-OFDM system are shown below.

Number of parallel channel = ISLT length = IFFT length = 64

Channel Spacing = 20 MHz which is used for 64 point ISLT or for IFFT

Symbol Rate = Sr = 312.5 (ksymbol/sec) = Carrier Spacing (Fc) (=20 MHz/64)

Symbol time = Ts = 1/Sr = 3.2 µsec

Guard time = TG = Ts/4 = 800 nsec

OFDM block length = Tf = TG + Ts = 4 µsec

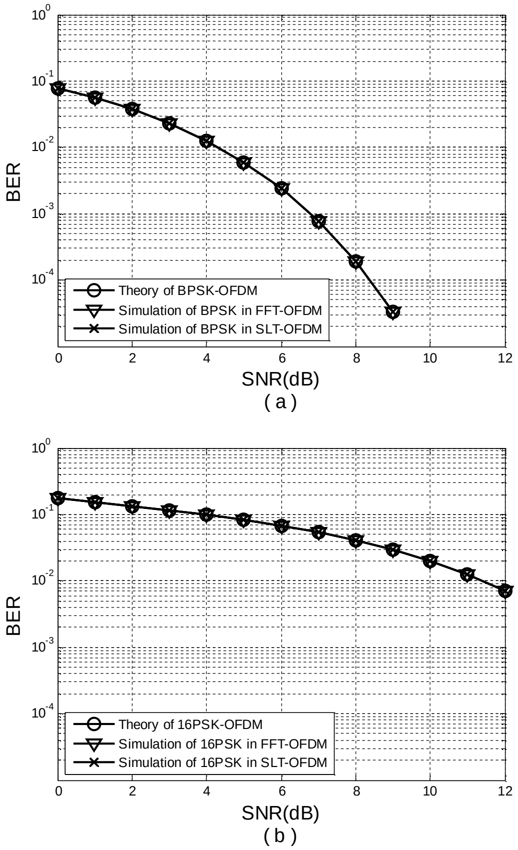
Rate in OFDM = 1/Tf = 250 (ksymbol/sec)

Number of OFDM symbol for one loop = 6

Pilot Symbol = 1 for 6 symbol

Modulation Schemes BPSK and 16PSK

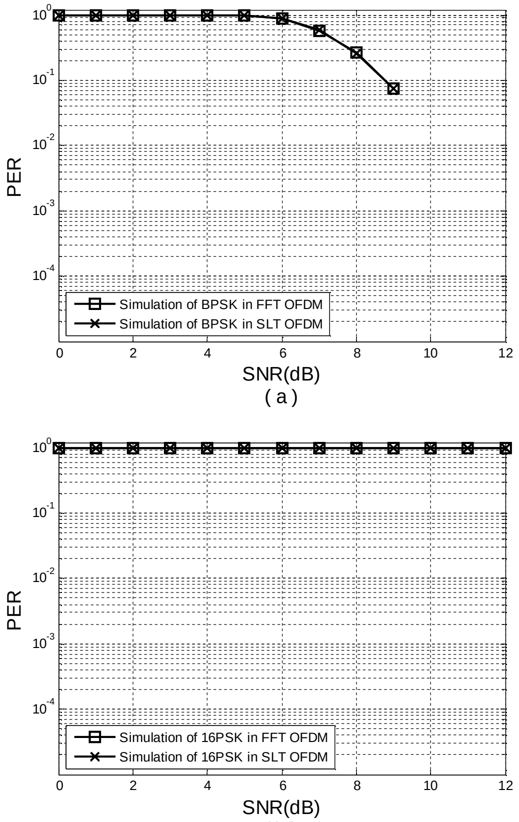
Figure (4) and Figure (5) illustrates the performance of the proposed SLT-based OFDM (SLT-OFDM) and the traditional FFT-based OFDM (FFT-OFDM) systems in AWGN channel compared with theoretical OFDM results for BPSK and 16PSK modulation. It is clearly shown that the BER decreases when we increase the SNR, which is normal because the signal becomes stronger than the noise. Also we can see from these two figures that the proposed SLT-based OFDM and FFT-based OFDM have almost the same BER and PER performance and close to theory BER results for OFDM system in AWGN channel.



(a)

(b)

Figure (4) BER performance of the proposed SLT-based OFDM system and the traditional FFT-based OFDM system in AWGN channel compared with theoretical OFDM results for (a) BPSK modulation (b) 16PSK modulation



(a)

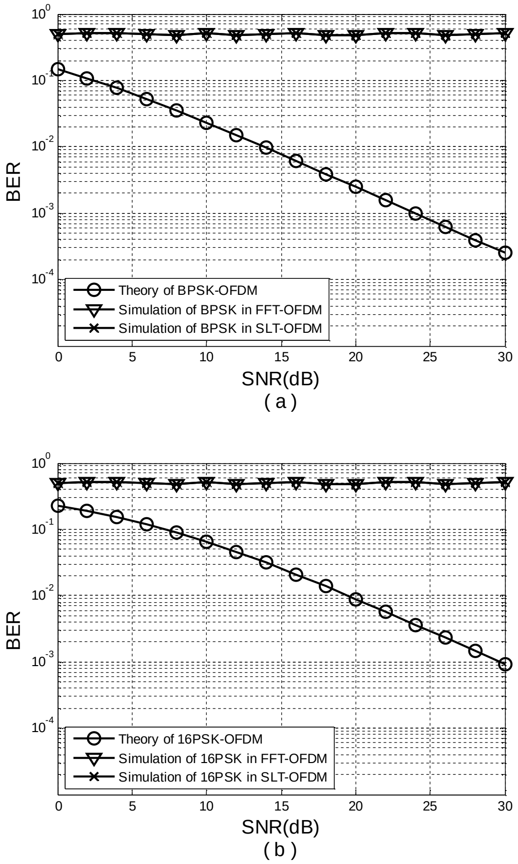
(b)

Figure (5) PER performance of the proposed SLT-based OFDM system and the traditional FFT-based OFDM system in AWGN channel for (a) BPSK modulation (b) 16PSK modulation

7-2 Performance Of The Proposed SLT-OFDM System In A Rayleigh Fading Channel With And Without Perfect Compensation

Fading is a more realistic mobile channel where multiple paths are received from the signal that is transmitted through the channel. This phenomenon introduces ISI (inter symbol interference) which is one of the major interference factors for a SLT-OFDM system that significantly degradates the system performance.

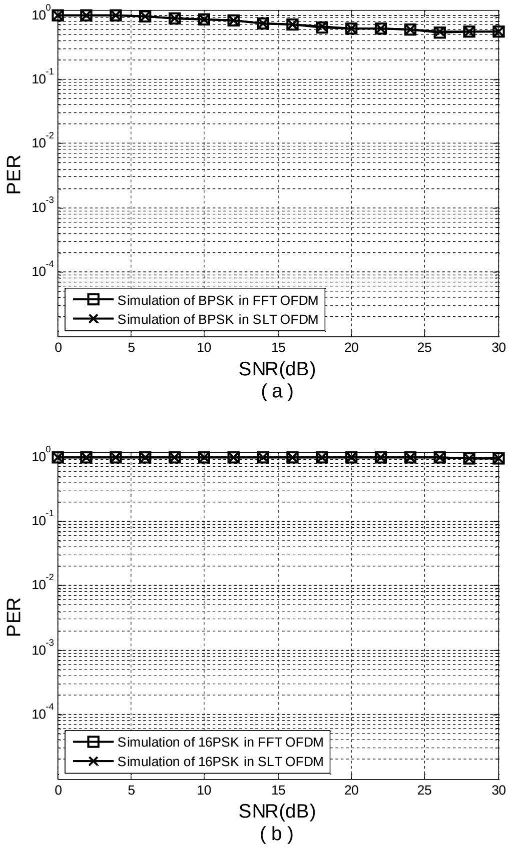
Figure (6) and Figure (7) show the BER and PER performance in a Rayleigh fading channel. The fading period is equal to 4 msec when the Doppler frequency shift equal to 250Hz (15 m/s @ 5 GHz). from simulation, if cannot compensate the amplitude and phase fluctuation caused by propagation characteristics, the data cannot be recovered, and both BER ≈ 0.5 and PER between (1 and 0.55) for all the values of SNR for two system BPSK-SLT-OFDM and BPSK-FFT-OFDM while the BER ≈ 0.5 and PER ≈ 1 for all values of SNR for two system 16PSK-SLT-OFDM and 16PSK-FFT-OFDM .



(a)

(b)

Figure (6) BER performance of the proposed SLT-based OFDM system and the traditional FFT-based OFDM system in a Rayleigh fading channel compared with theoretical OFDM results for (a) BPSK modulation(without compensation) (b) 16PSK modulation(without compensation).



(a)

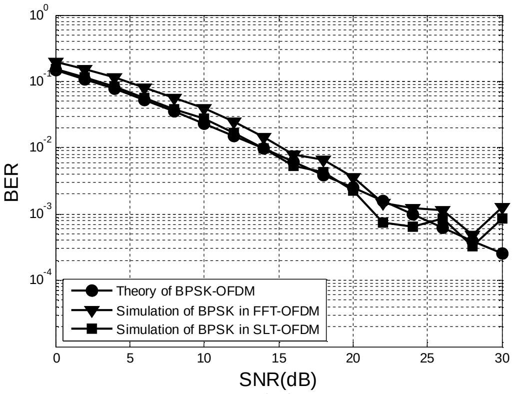
(b)

Figure (7) PER performance of the proposed SLT-based OFDM system and the traditional FFT-based OFDM system in a Rayleigh fading channel compared with theoretical OFDM results for (a) BPSK modulation (b) 16PSK modulation

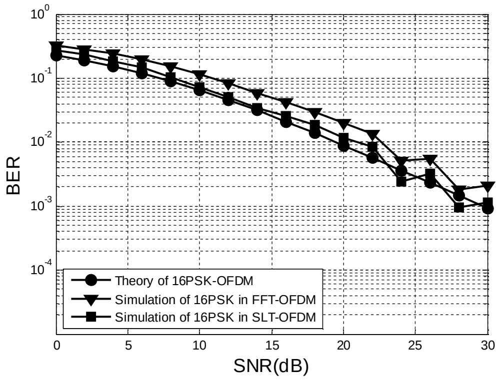
Figure (8) and Figure(9) show the BER and PER performance of the proposed SLT-based OFDM (SLT-OFDM) and the traditional FFT-based OFDM (FFT-OFDM) compared with the theoretical results for the OFDM system in a Rayleigh fading channel which have a Doppler frequency shift equal to 250Hz. To obtain real OFDM simulation we add 11 zeros in the center of data & one zero at the beginning (over sampling present) before fed the modulated data into the 64-point ISLT.[1,5]

In this simulation, we assume that an ideal channel estimation is achieved (perfect compensation). The proposed SLT based OFDM has much better BER performance than the FFT based -OFDM, since the filters in the SLT depend on the wavelet functions. This is a reflection of the fact that the orthogonal bases of the Slantlet are more significant than the orthogonal bases used in FFT which are capable to reduce the intersymbol interference (ISI) and intercarrier interference (ICI) which are lead to loss the orthogonality between the carriers as a result of multipath propagation over the wireless fading channels. So that, the results of The proposed SLT-OFDM system operates at its optimum BER performance with traditional FFT-OFDM system.

It is also clear that the BER of the proposed SLT-OFDM system with BPSK modulation is about 2dB better than that of the FFT-OFDM system with BPSK modulation for all values of SNR, moreover. The proposed SLT-OFDM system with 16PSK modulation is about 2.5dB over than that of the FFT-OFDM system with 16PSK modulation for all values of SNR

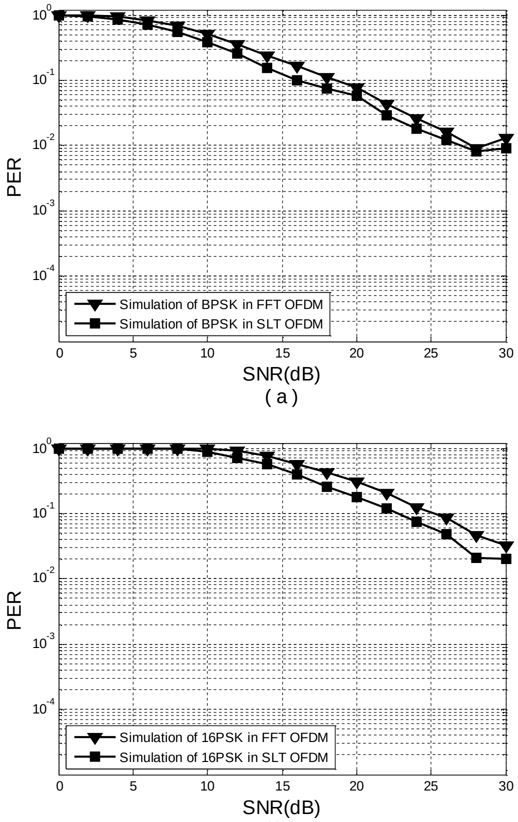


(a)



(b)

Figure (8) BER performance of the proposed SLT-based OFDM and FFT-based OFDM system in a Rayleigh fading channel with perfect compensation compared with theoretical OFDM results for (a) BPSK modulation (b) 16PSK modulation.



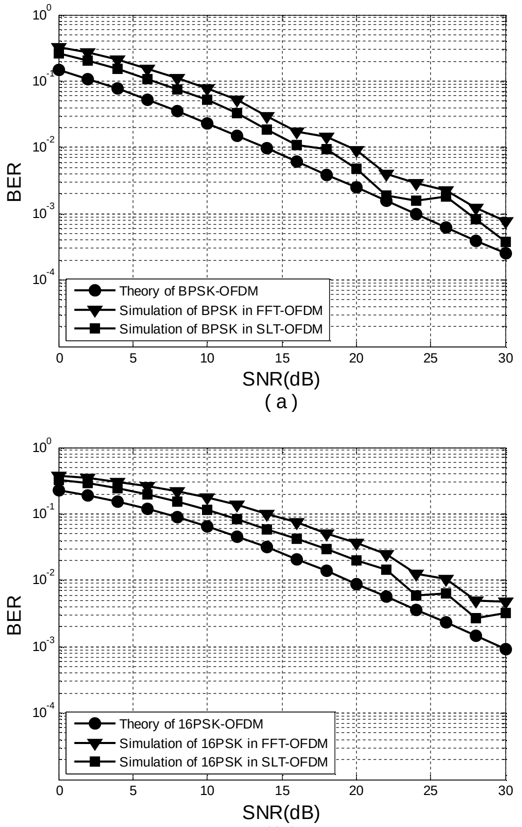
(a)

(b)

Figure (9) PER performance of the proposed SLT-based OFDM and FFT-based OFDM system in a Rayleigh fading channel with perfect compensation for (a) BPSK modulation (b) 16PSK modulation

7-3 Performance Of The Proposed SLT-OFDM System In a Rayleigh Fading Channel with Pilot Symbol-Aided OFDM Modulation

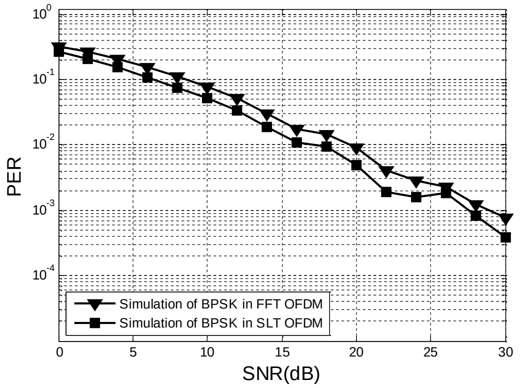
In this simulation, we use one channel estimation symbol (pilot symbol) and six transmitted data symbols as one frame (packet) unit. Figure (10) and Figure (11) show the BER performance for the proposed SLT-OFDM system and traditional FFT-OFDM system compared with the theoretical results for OFDM system in a Rayleigh fading channel for channel estimation compensation. If a pilot signal for the proposed SLT- OFDM transmission system with BPSK modulation is used, approximately 3 dB shift form the theoretical result is obtained because of the pilot data of 1/7 in one frame (packet) unit & use high value of Doppler frequency shift (fd=250) so the fading period is 4 ms. Also the channel estimation is not accurate enough to follow the fast fading. While, for pilot symbol FFT-OFDM transmission system with BPSK modulation approximately 5dB shift form the theoretical result is obtained. Also, we can see that the proposed SLT-OFDM system with BPSK modulation is about 2 dB better than that of the FFT-OFDM system for all values of SNR. Moreover, for pilot symbol SLT-OFDM transmission system with 16PSK modulation, approximately 3dB shift from the theoretical result is obtained. While for the FFT-OFDM transmission system with 16PSK modulation approximately 6dB shift from the theoretical result is obtained. It is also clear that the proposed SLT-OFDM system with 16PSK modulation is about 3dB better than that of the FFT-OFDM system for all values of SNR dB.



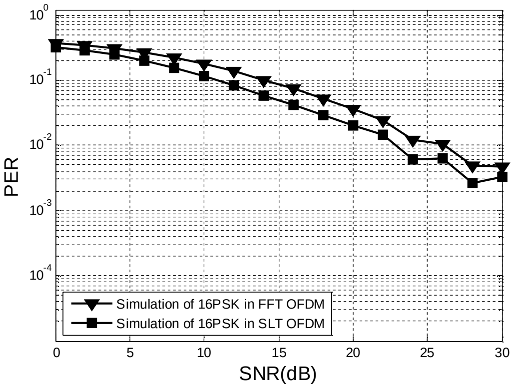
(a)

(b)

Figure (10) BER performance of the proposed SLT-based OFDM system and FFT-based OFDM system in a Rayleigh fading channel with Pilot Symbol-Aided compared with theoretical OFDM results for (a) BPSK modulation (b) 16PSK modulation



(a)



(b)

Figure (11) PER performance of the proposed SLT-based OFDM system and FFT-based OFDM system in a Rayleigh fading channel with Pilot Symbol-Aided for (a) BPSK modulation (b) 16PSK modulation

7.4 Performance Of The Proposed LDPC Codes For The SLT-OFDM System With Pilot Symbol Aided OFDM Modulation

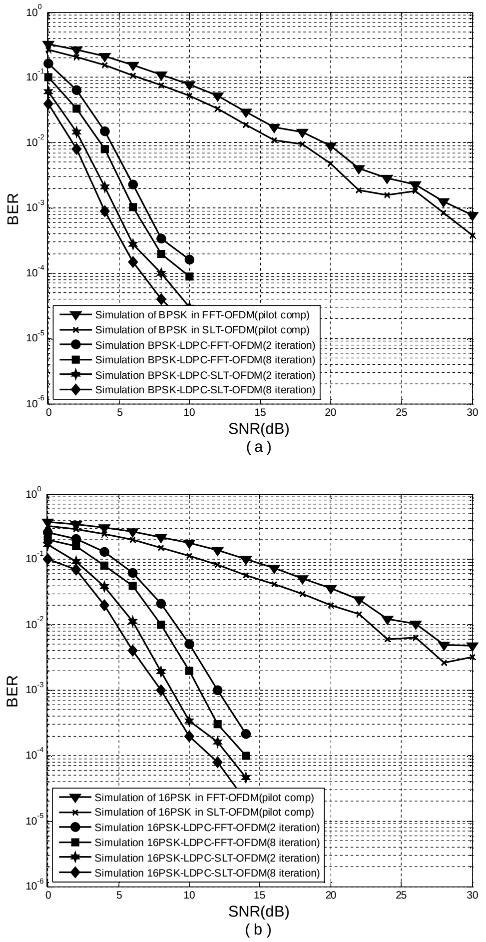
In this section, we evaluate the bit error rate (BER) of the proposed LDPC-SLT-OFDM system with BPSK and 16 PSK modulation using the Gray mapping in a Rayleigh fading channel with pilot channel estimation. We use (20,10)LDPC code Rate 1/2 with column weight of 3 and set the number of iterations in decoding to 2 and 8 and compare the results with the LDPC-FFT-OFDM system.

Figure-3 shows the block diagram of proposed LDPC-SLT-OFDM system for BPSK and 16PSK modulation over a Rayleigh fading channel with pilot system aided channel estimation. First, a block of k bits information data is encoded by a rate 1/2 LDPC code. The encoder output then passes through the modulator which modulates the data using BPSK or 16PSK modulation. The modulated data is converted from serial to parallel and mapped on the subcarriers using an inverse SLT. Each OFDM block is prefixed by a cyclic copy of the last few samples in the same block. At the receiver the inverse operation is performed. After LDPC code is decoded the data bit by using sum-product algorithm and then the bit error rate (BER) is calculated.

In a multipath fading channel, some subcarriers of OFDM may be completely lost because of the deep fades. Hence, it is expected that lots of errors fix on continuous some subcarriers and the two dimensional errors in both time and frequency domains occur. So, LDPC codes can compensate for two dimensional errors in both time and frequency domains for the OFDM system.

Figure 12, shows the BER performance of the LDPC-SLT-OFDM system and LDPC-FFT-OFDM system with BPSK and 16PSK modulation. With each iteration in the figures, the estimation of the message bits improves, and they usually converge to a correct estimate of the message. The number of corrected error increases as the number of iterations increases. However, the improvement of the estimation does not increase linearly, and so, in practice, it is enough to utilize a reasonable small number of iterations to achieve acceptable performance. Therefore, as the number of iterations for the iterative LDPC code decoding algorithm increases, the LDPC decoder performs significantly better.

From this figure, the BER performance of the LDPC-SLT-OFDM system with BPSK modulation is about 3dB better than that of the LDPC-FFT-OFDM system after 2 and 8 iteration and for all values of SNR in a Rayleigh fading channel with pilot symbol aided channel estimation. The BER performance of the LDPC-SLT-OFDM system with 16PSK modulation is about 4dB better than that of the LDPC-FFT-OFDM system after 2 and 8 iteration and for all values of SNR in a Rayleigh fading channel with pilot symbol aided channel estimation. Therefore, the overall performance of the proposed LDPC code SLT OFDM is considered very well in operation under fading channel which is also efficient in terms of power consumption as compared to the LDPC code FFT-OFDM system.



(a)

(b)

Figure (12) BER performance of the proposed LDPC codes for the proposed SLT-based OFDM system and the proposed LDPC codes for FFT-based OFDM system in a Rayleigh fading channel with Pilot compensation with 2 and 8 iterations for (a) BPSK modulation (b) 16PSK modulation

From the figure-12(a) the coding gain at BER = $7*10^{-4}$ between uncoded traditional FFT-OFDM system and coded LDPC-FFT-OFDM system with BPSK modulation and with pilot compensation in a Rayleigh fading channel is about 22.5 dB for 2 iteration and about 23 dB for 8 iteration. While the coding gain at BER = $7*10^{-4}$ between uncoded proposed SLT-OFDM system and coded LDPC-SLT-OFDM system with BPSK modulation and with pilot compensation in a Rayleigh fading channel is about 23 dB for 2 iteration and about 24 dB for 8 iteration.

Finally, the coding gain between the proposed LDPC-SLT-OFDM and LDPC-FFT-OFDM is about 2.5dB for 2 iteration and about 3dB for 8 iteration.

While, from the figure-12(b) the coding gain at BER = $5*10^{-3}$ between uncoded traditional FFT-OFDM system and coded LDPC-FFT-OFDM system with 16PSK modulation and with pilot compensation in a Rayleigh fading channel is about 18 dB for 2 iteration and about 19 dB for 8 iteration. While the coding gain at BER = $5*10^{-3}$ between uncoded proposed SLT-OFDM system and coded LDPC-SLT-OFDM system with 16PSK modulation and with pilot compensation in a Rayleigh fading channel is about 20 dB for 2 iteration and about 21 dB for 8 iteration.

Finally, the coding gain between proposed LDPC-SLT-OFDM and LDPC-FFT-OFDM is about 3dB for 2 iteration and about 3dB for 8 iteration.

7- Conclusions

In this paper, an SLT for OFDM system is proposed to improve the BER performance on a Rayleigh fading channel. The SLT is less frequency sensitive than the equivalent DWT or FFT due to the shorter length of the SLT filters. The LDPC-SLT-OFDM system with BPSK and 16PSK modulation using gray mapping has a better error rate performance and is more effective than the LDPC-FFT-OFDM system with BPSK and 16PSK modulation on a Rayleigh fading channel with pilot channel estimation in the term of iterations for the decoding algorithm. The reason for this improvement on a Rayleigh fading channel could be explained by the decoding algorithm. The proposed system employs the sum product algorithm as a decoding algorithm. The sum product algorithm exchanges likelihoods among frequency and time directions, so it can compensate for the two dimensional errors in both frequency and time domains. Thus, the LDPC codes are effective to improve the error performance of the proposed SLT-OFDM system on a Rayleigh fading channel.

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