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Channel Estimation Using Pilot Optimization in OFDM Systems

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is a modulation format which is being used for many latest wireless and telecommunication standards. It is widely applied in wireless communication system due to its high rate transmission capability with high bandwidth efficiency and its robustness with regard to multipath fading and delay. Channel estimation is an integral part of OFDM system, it is critical to understand the basis of channel estimation techniques for OFDM system. So that, the most appropriate method should be applied. Recent advances in compressed sensing (CS) have demonstrated the application of sparse recovery to channel estimation. It means that sparse channel estimation can be more efficient than the conventional channel estimation. Some existing conventional methods are equidistant scheme and random search method. Since it has high mean squared error and system complexity, there is a need to introduce a new system. Because multipath wireless channels are highly sparse in nature. In this paper, we consider a pilot design based on the mutual incoherence property (MIP) for sparse channel estimation to improve the estimation performance. Here, we propose a pilot design scheme called as Stochastic Sequential Search (SSS), to obtain a near optimal pilot pattern. Stochastic sequential search works on the basis of two loops of iteration, which reduces sparse nature of the channel by pilot insertion. Simulation result will show the comparison graph of various parameters of proposed system and those obtained with the existing system. Moreover stochastic scheme outperforms the existing method in terms of channel estimation performance.

Keywords: OFDM, MIMO, MIP, PILOT, BER, ICI, CS.

I. Introduction

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. Wireless operations permit services, such as long- range communications that are impossible or impractical to implement with the use of wires. (e.g. radio transmitters and receivers, remote controls, etc.) Which use some form of energy (e.g. radio waves, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances. Orthogonal frequency division multiplexing is a method in which we can transmit a huge amount of data by efficiently using the given bandwidth and without any interference.

In a basic communication system, the data are modulated onto a single carrier frequency. The available bandwidth is then totally occupied by each symbol. This kind of system can lead to inter-symbol-interference (ISI) in case of frequency selective channel. The basic idea of OFDM is to divide the available spectrum into several orthogonal sub channels so that each narrowband sub channels experiences almost flat fading. Orthogonal frequency division multiplexing (OFDM) is becoming the chosen modulation technique for wireless communications. OFDM can provide large data rates with sufficient robustness to radio channel impairments. Wi-Fi is a wireless local area network that enables portable computing devices to connect easily to the Internet. Standardized as IEEE 802.11; Wi-Fi approaches speeds of some types of wired Ethernet.

Cellular data service offers coverage within a range of 10-15 miles from the nearest cell site. Speeds have increased as technologies have evolved, from earlier technologies such as GSM, CDMA and GPRS, to 3G networks such as W-CDMA, EDGE or CDMA2000. Common forms of diversity are time diversity (due to Doppler spread) and frequency diversity (due to delay spread). In recent years the use of spatial (or antenna) diversity has become very popular, which is mostly due to the fact that it can be provided without loss in spectral

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efficiency. Receive diversity, that is, the use of multiple antennas on the receive side of a wireless link, is a well-studied subject. Channel is a most general sense can describe everything from the source to the sink of the radio signal including the physical medium. Channel model is a mathematical representation of the transfer characteristics of the physical medium [9].

The performance of OFDM system can be enhanced by allowing for coherent demodulation when a precise channel estimation algorithm is employed. In OFDM transmission system, several channel estimation techniques have been proposed under the assumption of a slow fading channel, in which the channel transfer function remain stable within one OFDM data block[4].Channel estimation is one of the important portions in communication systems. An exact channel estimation algorithm should encompass both the time and frequency domain characteristics for the OFDM systems [7].Channel state information is vital for data detection and also for channel equalization [10]. It can be obtained in different ways that is training symbols that are a priori known at the receiver, whereas the other is blind, relies only on the established symbols, and it acquires CSI by exploiting statistical information and/or transmitted symbol properties like finite alphabet, constant modulus. Typical procedures for identifying the channel based on training utilize multiple OFDM symbols that consist completely of pilot symbols. For single-input single-output (SISO) systems, this approach can be found whereas for multiple-input multiple-output (MIMO) system.IEEE802.16e which recommended the use of two-dimensional discrete pilot subcarriers, and continuous pilot is divided into two cases: the block pilot distribution and comb pilot distribution. In the block pilot insertion mode, to divide OFDM symbols into m group, the first OFDM symbol is to transmit pilot signal in each group, and the other OFDM symbols transmit data information, such an estimate will use all sub-channels information. Features of the program is pilot symbol covers all frequencies, so the pilot symbols can be effective against frequency selective fading, but more sensitive to the impact of the fast varying channels.

Pilots are inserted for channel estimation and coherent detection at receiver side. Pilot symbol aided channel estimation must be used to track the variation of the channel. LS method was chosen for initial channel estimation in pilots at receiver. Pilot symbols facilitate channel estimation, they reduce the transmit energy for data symbols per OFDM symbol under a fixed total transmit power constraint. The effect of pilot symbol aided channel estimation in MIMO OFDM systems with three different types of pilot patterns. Random pilot, Orthogonal pilot and Optimized pilot. The optimal placement and power of pilot signals for maximizing capacity and minimize the bit error rate. We analyze the channel estimation error, according to three different pilot patterns to see how the channel estimation error affects the BER of MIMO OFDM systems. The interference from the antenna and sub carriers cause a large amount of interference we consider three pilot transmit schemes that eliminate this in order to allow better performance.

II. OVERVIEW OF PSO

The PSO is robust stochastic optimization technique based on the movement and intelligence of swarms. It is very efficient optimization algorithm by searching an entire high dimensional problem space [4]. The advantages of the PSO are the simple implementation and it's quickly convergence ability. In PSO, simple software agent called as particles that represent as potential solutions are placed in the search space of function and evaluate the objective function at their current location [2]. Each particle searches for better position in the search space by changing velocity according to rules. Each particle i has position and velocity Where D is dimension of solution space. Initially, velocity and position of particles are generated randomly in search space.

At each iteration, the velocity and the position of particle i on dimension are updated. The inertia weight w is employed to control the impact of the previous history of velocities on the current velocity [3], thereby influencing the tradeoffs between global and local exploration abilities of the flying points. A large inertia weight w facilitates a global search, while a small inertia weights facilitates a local search [9]. Suitable selection of the inertia weights provides a balance between global and local exploration abilities and thus requires less iteration on the average to find the optimum. In this paper, inertia weight is linearly decreased from w max to w min according to,

$$W=\frac{W_{max}-(W_{max}\times W_{min})}{Iteration_{max}}\times iteration$$

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At first, the particles that represent pilot positions are initialized at random values between 0 and 255 for the system which has 256 subcarriers. All the possible combinations of particle positions are tested using fitness function that is Rmax / P. If the fitness of particle's current position is better than previous best position, the velocity and position of particle are updated.

III. Pilot Allocation In Sparsity Based Estimation Methods

For our simulations in this part, we generated a random 3-tap channel with varying fading parameters in each OFDM block and averaged the results over 5000 runs. The MSE of the estimated channel for two different methods of pilot allocation [3]. In the first scenario, the pilots are chosen uniformly at random for each block; in our proposed scheme, the pilots are arranged according to a (73, 9, 1) cyclic difference set and its cyclic shifts for different OFDM blocks.

$$CRB - S = \sigma^2 trace\left(\left(F_{p,A} H F_{p,A}\right)^{-1}\right)$$

Where σ^2 is the noise variance and $\mathbf{F}_{p,\Lambda}$ is the sub matrix of $\mathbf{F}_p$ obtained by keeping the columns corresponding to the channel taps. This lower bound is a fair criterion to measure the quality of our pilot allocation method, since it is the MSE of an estimator that knows the exact location of the channel taps. Therefore, in OMP channel estimation, if we select pilot locations properly, the maximum cross correlation between the columns of $\mathbf{F}_p$ becomes small. Hence, the columns of the resultant measurement matrix in (3) become less correlated which makes it easier to detect and estimate the CIR.

A. Interpolation Techniques

Without going back to time domain channel frequency response for each subcarrier can be found by using interpolation techniques. In comb-type pilot based channel estimation, an efficient interpolation technique is necessary in order to estimate channel at data sub-carriers by using channel information at pilot sub-carriers. Channel transfer function at pilot sub-carriers estimated from (4.16) in LSE sense. The estimated transfer function at pilot frequencies will be

$$\widehat{H_p}(k) = \frac{Y(k)}{\sqrt{\varepsilon_p} X_p(k)} \ for\ k \in \beth_p$$

1. Linear Interpolation

In the linear interpolation algorithm, two successive pilot sub-carriers are used to determine the channel response for data sub-carriers that are located in between the pilots. The channel estimation at data-carriers k, mL < k < (m +) 1 L is given by

$$H(n) = H_d(n)$$
$$= H_{d(mL+l)} \quad 0 \le l \le L$$
$$= \left(H_p(m+1) - H_p(m)\right)\frac{l}{L} + H_p(m)$$

2.Spline and Cubic Interpolation

Spline and Cubic interpolations are done by using "interp1" function of MATLAB. Spline and Cubic interpolations produce a smooth and continuous polynomial fitted to given data points. Spline interpolations works better than linear interpolation for comb pilot arrangement

3. Equidistant Pilot Insertion Method

In this method (pilot signals) which are null signals, is equally placed between the carriers. The pilots are inserted in two ways namely block and comb type. It is a basic method which is overcome by random search method. Channel impulse response is reconstructed by frequency domain channel response at the carrier. It attains less latency and minimization of computational complexity. High performance up to 30db SNR.

IV. System Model

With the ever growing demand of this generation, need for high speed communication has become an utmost priority. Various multicarrier modulation techniques have evolved in order to meet these demands, few notable among them being Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM). Orthogonal Frequency Division Multiplexing is a frequency – division multiplexing (FDM) scheme utilized as a digital multi – carrier modulation method. A large number of closely spaced orthogonal sub – carriers is used to carry data. The data is divided into several parallel streams of channels, one for each sub – carriers. Each sub – carrier is modulated with a conventional modulation scheme (such as QPSK) at a low symbol rate, maintaining total data rates similar to the conventional single carrier modulation schemes in the same bandwidth.

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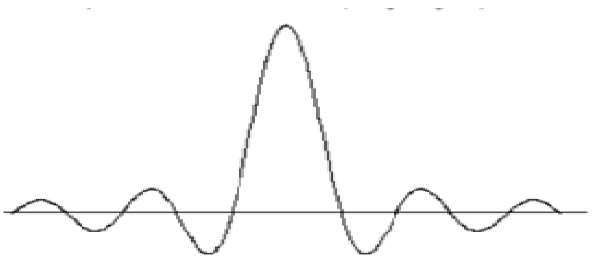

Figure 4.1 OFDM Spectrum in single carrier

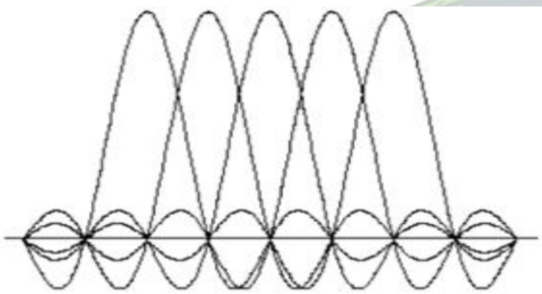

Figure 4.2 OFDM Spectrum in multi carriers

Orthogonal frequency division multiplexing (OFDM) is a widely adopted modulation technique for broadband communication systems. Orthogonal Frequency Division Multiplexing is a special form of multicarrier modulation which is particularly suited for transmission over a dispersive channel. Here the different carriers are orthogonal to each other, that is, they are totally independent of one another. This is achieved by placing the carrier exactly at the nulls in the modulation spectra of each other

4.1 Orthogonality of Sub-Channel Carriers

OFDM communications systems are able to more effectively utilize the frequency spectrum through overlapping sub-carriers.

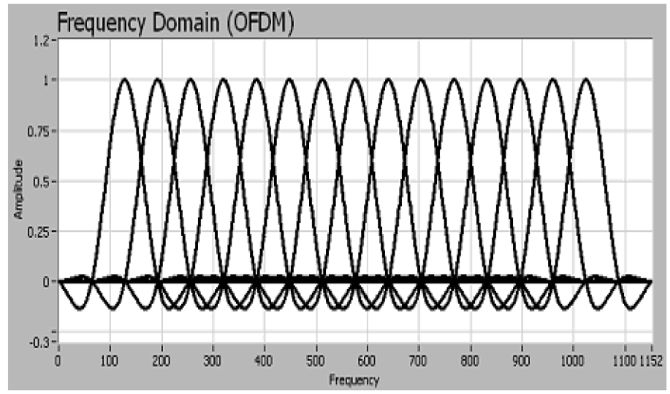

Figure 4.3 Orthogonality of Sub Channel Carriers

These sub-carriers are able to partially overlap without interfering with adjacent sub-carriers because the maximum power of each sub-carrier corresponds directly with the minimum power of each adjacent channel. Below, we illustrate the frequency domain of an OFDM [6] system graphically. As you can see from the figure, each sub-carrier is represented by a different peak. In addition, the peak of each sub-carrier corresponds directly with the zero crossing of all channels. Note that OFDM channels are different from band limited FDM channels how they apply a pulse-shaping filter. With FDM systems, a sinc-shaped pulse is applied in the time domain to shape each individual symbol and prevent ISI. With OFDM systems, a sinc-shaped pulse is applied in the frequency domain of each channel. As a result each sub carrier is orthogonal to one another.

4.2 OFDM System Model

To generate OFDM successfully the relationship between all the carriers must be carefully controlled to maintain the orthogonality of the carriers. For this reason, OFDM is generated by firstly choosing the spectrum required based on the input data, and modulation scheme used. Each carrier to be produced is assigned same data to transmit. The required amplitude and phase of them are calculated based on the modulation scheme [8]. The required spectrum is then converted back to its time domain signal using an Inverse Fourier Transform (IFT).

In most applications, an Inverse Fast Fourier Transform (IFFT) is used. The IFFT performs the transformation very efficiently and provides a simple way of ensuring the carrier signals produced are orthogonal. The Fast Fourier Transform (FFT) transforms acyclic time

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domain signal into its equivalent frequency spectrum. This is done by finding the equivalent waveform, generated by a sum of orthogonal sinusoidal components.

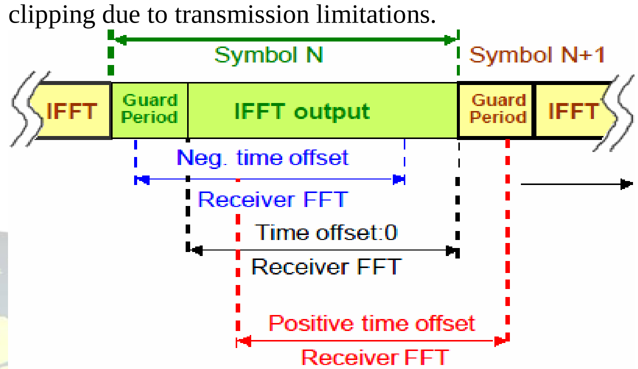
In digital communications, information is expressed in the form of bits. The term symbol refers to a collection, in various sizes, of bits [6]. OFDM data are generated by taking symbols in the spectral space using *M*-PSK, QAM, etc, and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). Since Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead [3]. Once the OFDM data are modulated to time signal, all carriers transmit in parallel to fully occupy the available frequency bandwidth [7]. During modulation, OFDM symbols are typically divided into frames, so that the data will be modulated frame by frame in order for the received signal be in sync with the receiver. Long symbol periods diminish the probability of having inter-symbol interference, but could not eliminate it. To make ISI nearly eliminated, a cyclic extension (or cyclic prefix) is added to each symbol period. An exact copy of a fraction of the cycle, typically 25% of the cycle, taken from the end is added to the front. This allows the demodulator to capture the symbol period with an uncertainty of up to the length of a cyclic extension and still obtain the correct information for the entire symbol period. A guard period, another name for the cyclic extension, is the amount of uncertainty allowed for the receiver to capture the starting point of a symbol period, such that the result of FFT still has the correct information.

4.3 OFDM Parameters and Characteristics

The number of carriers in an OFDM system is not only limited by the available spectral bandwidth, but also by the IFFT size (the relationship is described by:

$$number\ of\ carriers \leq \frac{ifft\_size}{2} - 2$$

Which is determined by the complexity of the system . The more complex (also more costly) the OFDM system is, the higher IFFT size it has; thus a higher number of carriers can be used, and higher data transmission rate achieved. The choice of *M*-PSK modulation varies the data rate and Bit Error Rate (BER). The higher order of PSK leads to larger symbol size, thus less number of symbols needed to be transmitted, and higher data rate is achieved. But this results in a higher BER since the range of 0-360 degrees of phases will be divided into more sub-regions, and the smaller size of sub-regions is required, thereby received phases have higher chances to be decoded incorrectly. OFDM signals have high peak-to-average ratio, therefore it has a relatively high tolerance of peak power clipping due to transmission limitations.



Symbol Period

- **Orthogonality**

The key to OFDM is maintaining orthogonality of the carriers. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy this criterion. Therefore, orthogonality is defined by:

$$\int_0^T \cos(2\pi n f_0 t)\cos(2\pi m f_0 t)dt = 0 \ \ (n \neq m)$$

Where *n* and *m* are two unequal integers; *f*o is the fundamental frequency; *T* is the period over which the integration is taken. For OFDM, *T* is one symbol period and *f*o set to to 1/*T* for optimal effectiveness.

Overview of This OFDM Simulation Project

Since MATLAB has a built-in function **"ifft()"** which performs Inverse Fast Fourier Transform, IFFT is opted for the development of this simulation. Six m-files are written to develop this MATLAB program of OFDM simulation. One of them is the main program script file, which is the only file that needs to be run, while other m-files will be invoked accordingly. A 256-grayscale bitmap image is required as the source input. Another bitmap image file will be generated at the end of the simulation as the output. ***Err_calc.mat*** *is* to archive the baseband data before the transmission, and be retrieved at the end of the simulation for the purpose of error calculations.***Ofdm_parameters.mat***is to archive the parameters initialized at the beginning of the simulation and reserve them for the receiver to use later. In the reality,

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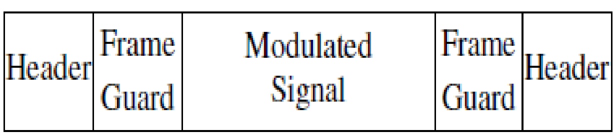
the receiver would always have these parameters; in this simulation, these parameters are configured by the user at the beginning, so they are passed to the receiver by ***Ofdm_parameters.mat***as if being preset in the receiver. ***Received.mat*** stores the time signal after it travels through the channel, and lets the receiver to read it directly.

4.3.1 OFDM Transmitter

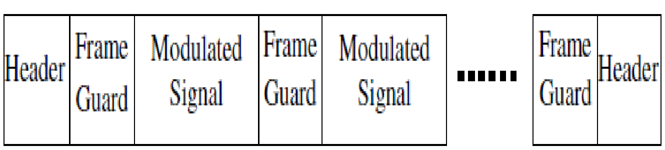
A) Frame Guards

The core of the OFDM transmitter is the modulator, which modulates the input data stream frame by frame. Data is divided into frames based on the variable symb_per_frame, which refers to the number of symbols per frame per carrier. It is defined by: symb_per_frame = ceil (2^13/carrier count). This limits the total number of symbols per frame (symb_per_frame * carrier count) within the interval of [2^13, 2*(2^13-1)], or [8192, 16382]. However, the number of carriers typically would not be much greater than 1000 in this simulation, thus the total number of symbols per frame would typically be under 10,000. This is an experimentally reasonable number of symbols that one frame should keep under for this MATLAB program to run efficiently; thereby symb_per_frame is defined by the equation shown above. If the total number of symbols in a data stream to be transmitted is less than the total number of symbols per frame, the data would not be divided into frames and would be modulated all at once.

Even if the data stream is not sufficiently long to be divided into multiple frames, two frame guards with all zero values and in a length of one symbol period are still added to both ends of the modulated time signal. This is to assist the receiver to locate the beginning of the substantial portion of the time signal.



Modulated Signal (single frame)



Modulated Signal (multiple frames)

From modulated signals with multiple frames, a frame guard is inserted in between any two adjacent frames as well as both ends of the cascaded time signal. Finally, a pair of headers is padded to both ends of the guarded series of frames. The headers are scaled to the RMS level of the modulated time signal.

B) Serial to Parallel Conversion

In an OFDM system, each channel can be broken into various subcarriers. The use of sub-carriers makes optimal use out of the frequency spectrum but also requires additional processing by the transmitter and receiver. This additional processing is necessary to convert a serial bit stream into several parallel bit streams to be divided among the individual carriers. Once the bit stream has been divided among the individual subcarriers, each sub-carrier is modulated as if it was an individual channel before all channels are combined back together and transmitted as a whole. The receiver performs the reverse process to divide the incoming signal into appropriate sub-carriers and then demodulating these individually before reconstructing the original bit stream.

4.3.2 OFDM Modulator

It is normal that the total number of transmitting data is not a multiple of the number of carriers. To convert the input data stream from serial to parallel, the modulator must pad a number of zeros to the end of the data stream in order for the data stream to fit into a 2-D matrix. Suppose a frame of data with 11,530 symbols is being transmitted by 400 carriers with a capacity of 30 symbols/carrier. 470 zeros are padded at the end in order for the data stream to form a 30-by-400 matrix, as shown in Figure. Each column in the 2-D matrix represents a carrier while each row represents one symbol period over all carriers.

- **16-QAM Modulation**

Quadrature Amplitude Modulation or QAM is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation such as PSK, although many forms of data modulation operate alongside each other.
Quadrature Amplitude Modulation, QAM is a signal in which two carriers shifted in phase by 90 degrees are modulated and the resultant output consists of both amplitude and phase variations. In view of the fact that both amplitude and phase variations are present it may also

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be considered as a mixture of amplitude and phase modulation.

A motivation for the use of quadrature amplitude modulation comes from the fact that a straight amplitude modulated signal, i.e. double sideband even with a suppressed carrier occupies twice the bandwidth of the modulating signal. This is very wasteful of the available frequency spectrum. QAM restores the balance by placing two independent double sideband suppressed carrier signals in the same spectrum as one ordinary double sideband supressed carrier signal.

4.3.3 IFFT: Spectral Space to Time Signal

The modulation of data into a complex waveform occurs at the Inverse Fast Fourier Transform (IFFT) stage of the transmitter. Here, the modulation scheme can be chosen completely independently of the specific channel being used and can be chosen based on the channel requirements. In fact, it is possible for each individual sub-carrier to use a different modulation scheme. The role of the IFFT is to modulate each sub-channel onto the appropriate carrier. Since each column of the QAM matrix represents a carrier, their values are stored to the columns of the IFFT matrix at the locations where their corresponding carriers should reside. Their conjugate values are stored to the columns corresponding to the locations of the conjugate carriers (refer to Figure 4). All other columns in the IFFT matrix are set to zero. To obtain the transmitting time signal matrix, Inverse Fast Fourier Transform (IFFT) of this matrix is taken. Only the real part of the IFFT result is useful, so the imaginary part is discarded.

Cyclic Prefix Insertion

Because wireless communications systems are susceptible to multi-path channel reflections, a cyclic prefix is added to reduce ISI. A cyclic prefix is a repetition of the first section of a symbol that is appended to the end of the symbol. In addition, it is important because it enables multi-path representations of the original signal to fade so that they do not interfere with the subsequent symbol.

- **Periodic Time Guard Insertion**

An exact copy of the last 25% portion of each symbol period (row of the matrix) is inserted to the beginning. This is the periodic time guard that helps the receiver to synchronize when demodulating each symbol period of the received signal. The matrix now becomes a modulated matrix. By converting it to a serial form, a modulated time signal for one frame of data is generated.

Communication Channel

Two properties of a typical communication channel are modelled. A variable clipping in this MATLAB program is set by the user. Peak power clipping is basically setting any data points with values over clipping below **peak power** to **clipping** below peak power. The peak-to-RMS ratios of the transmitted signal before and after the channel are shown for a comparison regarding this peak power clipping effect.

Channel noise is modelled by adding a white Gaussian noise (AWGN) defined by:

$$\sigma \text{ of } AWGN = \sqrt{\frac{\text{variance of the modulated signal}}{\text{linear } SNR}}$$

It has a mean of zero and a standard deviation equalling the square root of the quotient of the variance of the signal over the linear Signal-to-Noise Ratio, the dB value of which is set by the user as well.

4.4 SSS ALGORITHM

Intuitively, by exhaustively searching over all possible pilot patterns, we can obtain the optimal pilot pattern with the minimum MIP. However, it is computationally prohibitive to search from all (N Np) candidates when N and Np are not very small. For example, if $N = 256$ and $Np = 12$, we have (256 12) = 1.27 × 10^{21}different pilot patterns, which form a huge search space. Apparently, the exhaustive search is not a good option for future energy-efficient wireless systems as it occupies a lot of computational resources that consume power and energy. Moreover, for those power-constrained mobile devices in cognitive radio networks, it is impractical to design the pilots using the exhaustive search. We now propose three low-complexity practical schemes to obtain near-optimal pilot patterns for any given pair of (N, Np) and for any value of L. The scheme is based on the stochastic search, which searches for the near-optimal pilot pattern with two loops of iterations.

The following stochastic search scheme consist of two levels of loops. In the outer loop, we randomly generate pilot patterns as the initializations of the inner loop. In the inner loop, we iteratively update the resulting pilot pattern in a greedy manner. For the pilot update in the inner loop, we propose two alternatives, i.e., the sequential

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search and the parallel search. We now explain these new stochastic schemes in detail as follows.
Given the maximum numbers of iterations for the outer and inner loops, i.e., $M1$ and $M2$, respectively, the SSS scheme is described as follows.

- In each iteration of the outer loop, we randomly generate a pilot pattern $\boldsymbol{p} \subset N = \{1, . . . , N\}$ as the initialization of the inner loop. In each iteration of the inner loop, we perform a sequential update of each entry of $\boldsymbol{p}$ according to the following step.
- For $k = 1, . . . , Np$, given the latest $\boldsymbol{p}$ from the last iteration, we update the kth entry of $\boldsymbol{p}$ with the best one selected from $N \backslash\{p(i)|i= 1, . . . , Np, i\_= k\}$,

For each initial pilot pattern in the outer loop, we obtain a corresponding optimized pilot pattern. With $M1$ outerloop iterations, we then obtain$M1$ optimized results, from which we select the one with the minimum MIP as the final output.

Note that for the inner loop, alternatively, we can continue updating $\boldsymbol{p}$ until it converges, meaning that it stops only when no update can be made after an inner-loop iteration completes. However, the computation time is difficult to control if the inner loop converges very slowly. Although this alternative approach may guarantee that the best result can be obtained after the inner-loop iterations, it may not be practical as the expected computational time is unknown. When we set a fixed number of inner-loop iterations as in Algorithm 1, it is possible that the pilot update converges earlier.

4.5 ERROR CALCULATIONS

- **Data loss**

"Input and Output," one or more of full rows of pixels may be missing at the output of the receiver. In such cases, this program would show the number of missing data and the total number of data transmitted, as well as the percentage of data loss, which is the quotient of the two.

- **Bit Error Rate (BER)**

Demodulated data is compared to the original baseband data to find the total number of errors. Dividing the total number of errors by total number of demodulated symbols, the bit-error-rate (BER) is found.

- **Phase Error**

During the OFDM demodulation, before being translated into symbol values the received phase matrix is archived for calculating the average phase error, which is defined by the difference between the received phase and the translated phase for the corresponding symbol before transmission.

- **Percent Error of Pixels in the Received Image**

All aforementioned error calculations are based on the OFDM symbols. What is more meaningful for the end-user of the OFDM communication system is the actual percent error of pixels in the received image. This is done by comparing the received image and original image pixel by pixel.

4.4.4 OFDM Receiver

Frame detector

A trunk of received signal in a selective length is processed by the frame detector (***ofdm_frame_detect.m***) in order to determine the start of the signal frame.A moving sum is taken over this sampled signal. The index of the minimum of the sampled signal is approximately the start of the frame guard while one symbol period further from this index is the approximate location for the start of the useful signal frame. The frame detector will then collect a moving sum of the input signal from about 10% of one symbol period earlier than the approximate start of the frame guard to about one third of s symbol period further than the approximate start of the useful signal frame. The first portion, with a length of one less than a symbol period of this moving sum is discarded. The first minimum of this moving sum is the detected start of the useful signal frame.

4.6 Demodulation Status Indicator

As mentioned, received OFDM signal is typically demodulated frame by frame. The OFDM receiver shows the progress of frames being demodulated. However, the total number of frames may vary by a wide range depending on the total amount of information transmitted via the OFDM system. It is a neat idea to keep the number of displays for this progress within a reasonable range. rem (k,max(floor(num_frame/10),1))==0 where k is the variable to indicate the k-th frame being modulated, and num_frame is the total number of frames. It means that for a total number of frames being 20 or more, it only displays the n-th frame when n is an integer multiple of the round-down integer of a tenth of the total number of frames; and for a total number of frames being 19 or less, it shows every frame that is being modulated. This would keep the total number of displays within the range from 11 to 19, provided that the total number of frames is more than 10; otherwise, it simply shows as many messages as the total number of frames.

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Periodic Time Guard Removal

"OFDM Modulator" shall continue to be used for illustration. After converting a frame of discrete time signal from serial to parallel, a length of 25% of a symbol period is discarded from all rows. Thus the remaining is then a number of discrete signals with the length of one symbol period lined up in parallel.

FFT: Time Signal to Spectral Space

Fast Fourier Transform (FFT) of the received time signal is taken. In FFT frequency domain is changed into time domain. This results the spectrum of the received signal. The columns in the locations of carriers are extracted to retrieve the complex matrix of the received data.

Parallel to Serial Conversion

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

V. Performance Analysis

A. BER VS SNR OF PILOT ESTIMATOR AT VARIOUS LENGTHS

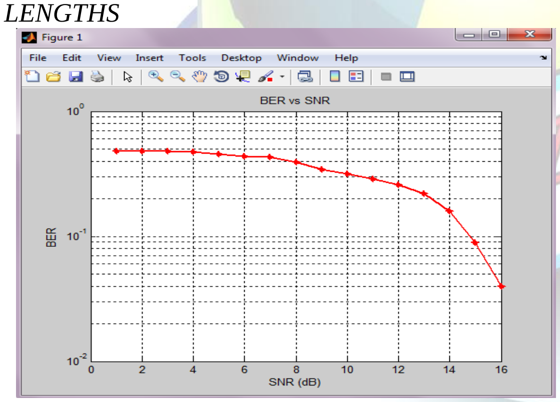

Fig 5.1 Estimation of pilot at 9bits

Above figure shows the curve which is drawn for BER and SNR values and describes the pilot estimator at 9 bits.

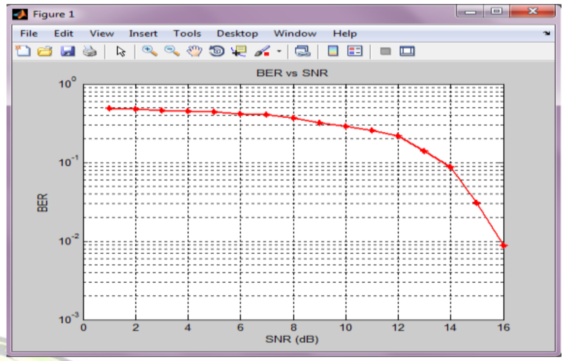

Fig 5.2 Estimation of pilot at 7 bits

Above shows the curve which is drawn for BER and SNR values and describes the pilot estimator at 7 bits.

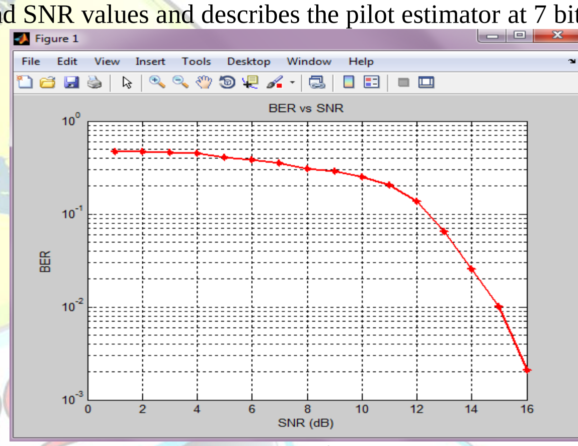

Fig 5.3 Estimation of pilot at 5 bits

Above shows the curve which is drawn for BER and SNR values and describes the pilot estimator at 5 bits.

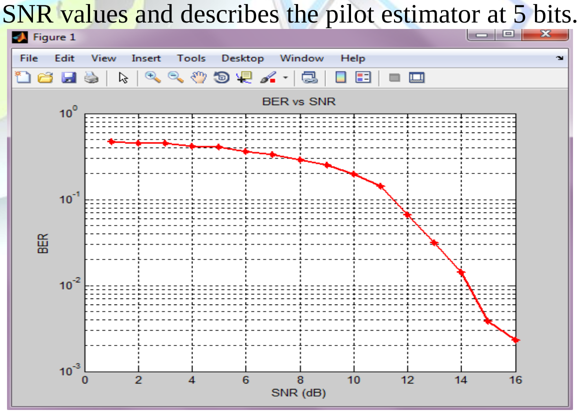

Fig 5.4 Estimation of pilot at 3 bits

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Above graph shows the curve which is drawn for BER and SNR values and describes the pilot estimator at 3 bits.

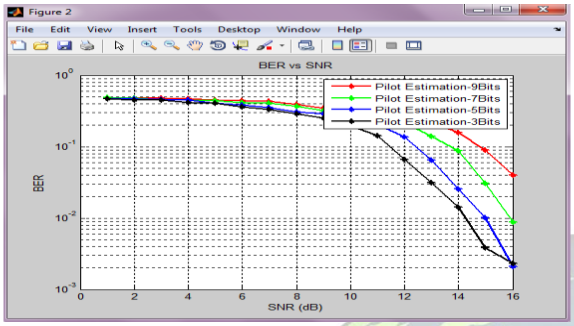

Fig. 5.5 Performance Comparisons of BER vs SNR for pilot carrier insertion

The above comparison graph shows the response of all the individual pilot estimator in a single graph. Each pilot estimator is of different length and generated between BER and SNR values.

B. BER VS SNR ESTIMATED USING SSS ALGORITHM

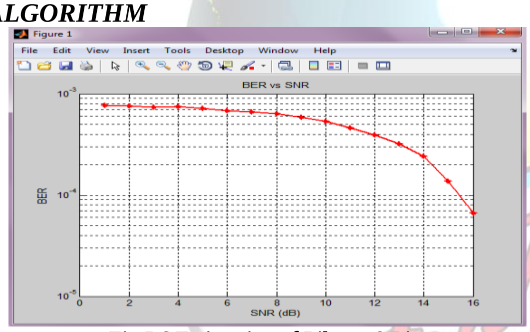

Fig 5.6 Estimation of Pilot at 9 Bits

Above graph shows the curve which is drawn for BER and SNR values and describes the pilot estimation using sss scheme at 9 bits.

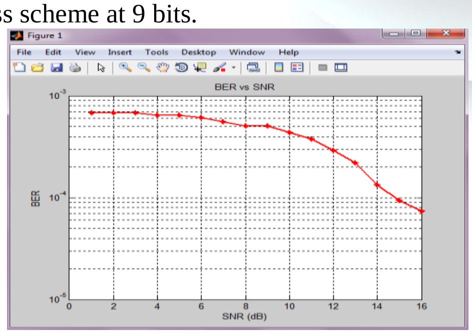

Fig 5.7 Estimation Of Pilot At 7 Bits

Above estimation graph showsshows the curve which is drawn for BER and SNR values and describes the pilot estimation using sss scheme at 7 bits.

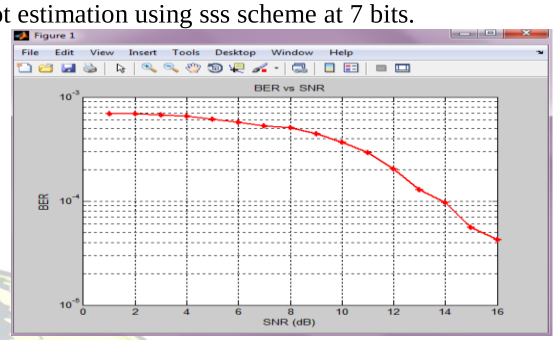

Fig 5.8 Estrimation of Pilot at 5 Bits

Above graph shows the curve which is drawn for BER and SNR values and describes the pilot estimation using sss scheme at 5 bits.

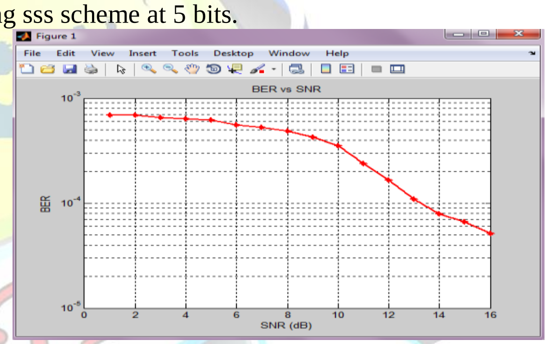

Fig 5.9 Estimation of Pilot at 3 Bits

Above graph shows the curve which is drawn for BER and SNR values and describes the pilot estimation using SSS scheme at 3 bits.

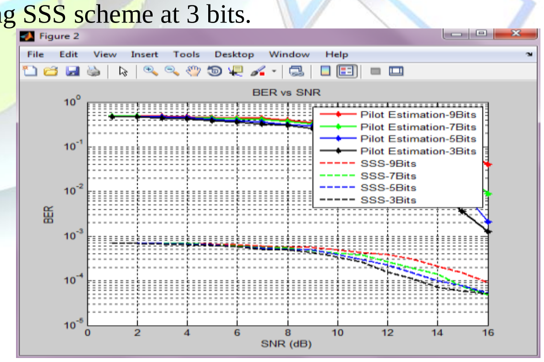

Fig 5. 10 BER Vs SNR of the Proposed and Random Pilot Allocation Methods

Above diagram shows the efficiency of using Stochastic Search Scheme over random pilot insertion.

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VI. CONCLUSION

The performance of OFDM systems depends on the signal quality seen by the receiver. The main advantage of the work is reduction in synchronization problem. Simulation results have demonstrated the effectiveness of the proposed schemes and have shown that the proposed system converge much faster than the cross entropy optimization and the exhaustive search schemes. Moreover the proposed system outperforms the existing system in terms of channel estimation performance. By using the proposed system, performance ratio will be higher than the existing methods and the condition to generate optimal pilot pattern can be satisfied. This work can be extended to incorporate parallel computation for the optimization process involved separately in each antenna of MIMO system which may reduce the computation time involved to compute the optimal values in each antenna. Therefore, it can be understood that the scope of this work is not confined to this research work alone. With advances in FPGA technology hardware based simulations have received more attention due to their high performance advantages over software based simulations .Error rates can be achieved within minutes for an implemented hardware solution. Therefore further research should be conducted to implement the optimization algorithms.

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