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Time Domain Signal Detection for MIMO OFDM

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Abstract-The MIMO techniques with OFDM is regarded as a promising solution for increasing data rates, for wireless access qualities of future wireless local area networks, fourth generation wireless communication systems, and for high capacity, as well as better performance.

Hence as part of continued research, in this paper an attempt is made to carry out modelling, analysis, channel matrix estimation, synchronization and simulation of MIMO-OFDM system. A time domain signal detection algorithm can be based on Second Order Statistics (SOS) proposed for MIMO-OFDM system over frequency selective fading channels. In this algorithm, an equalizer is first inserted to reduce the MIMO channels to ones with channel length shorter than or equal to the Cyclic Prefix (CP) length. A system model in which the ith received OFDM block left shifted by j samples introduced.

MIMO OFDM system model which uses the equalizer can be designed using SOS of the received signal vector to cancel the most of the Inter Symbol Interference (ISI). The transmitted signals are then detected from the equalizer output. In the proposed algorithm, only 2P (P transmitted antennas / users in the MIMO-OFDM system) columns of the channel matrix need to be estimated and channel length estimation is unnecessary, which is an advantage over an existing algorithms.

In addition, the proposed algorithm is applicable for irrespective of whether the channel length is shorter than, equal to or longer than the CP length. Simulation results verify the effectiveness of the proposed algorithm and shows that it out performs the existing one in all cases.

Keywords: Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Cyclic Prefix (CP), second – order statistics (SOS), Inter symbol Interference (ISI).

I. Introduction

Multiple input multiple outputs (MIMO) using multiple antennas at both transmit and receive ends becomes an important system for future wireless Communications [1]–[5] as it has the potential to greatly increase the system capacity without extra bandwidth. Generally, MIMO is applied in two situations. One is in Space-Time Coding (STC) systems where the transmission quality [Bit-Error Rate (BER)] is improved due to spatial diversity. The other is in spatial multiplexing or spatial multiple access systems where independent data streams are transmitted over different antennas, thus increasing the transmission rate or improving the system capacity. The MIMO technique can be designed with multiple antennas at both the transmitter and the receiver (i.e., a MIMO system). MIMO can be sub-divided into three main categories. So the functions of the MIMO techniques are Pre-Coding, Spatial Multiplexing and Diversity.

Orthogonal Frequency Division Multiplexing (OFDM) technique has been widely utilized in Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), and broadband wireless local area networks (IEEE 802.11a) [5]–[8], due to its ability to resist frequency selective fading. It is, therefore, desirable to combine OFDM with MIMO for high system capacity, as well as better performance. A lot of research interest has thus been attracted to MIMO OFDM systems in recent years [9] - [15].

In MIMO OFDM systems over frequency selective fading channels, signal detection can easily implemented by a set of parallel per sub carrier signal detectors applicable to flat fading channels when the channel length is shorter than or equal to the cyclic prefix (CP) length. However, when the channel length is longer than the CP length, Inter Block Interference (IBI) occurs and the orthogonal property of sub carriers will be destroyed, resulting in substantial performance degradation of the signal detection algorithm. In this paper, a Time-domain signal detection algorithm based on second-order statistics

(SOS) is proposed for general MIMO-OFDM systems over frequency selective channels.

A new system model is first introduced in which the *ith* received OFDM block is left shifted by samples. The new system model has certain structural properties that enable an equalizer to be designed to cancel most of the Inter Symbol Interference (ISI) using SOS of the received signals. At the output of the equalizer, only two paths of the transmitted signals are retained and the signals can readily be detected. Due to the special structure of the new system model, it turns out that only columns of the channel matrix need to be estimated. It follows that the minimum number of pilot symbols required to estimate the columns of the channel matrix is (compared with and is independent of the channel length. It also means that channel length estimation is unnecessary, which implies that the proposed algorithm has substantial advantage, computationally as well as avoiding performance degradation due to channel length estimation error, over existing algorithms [17], [18]. Furthermore, the proposed algorithm is applicable irrespective of whether the channel length is shorter than, equal to or longer than the CP length. Simulation results confirm the effectiveness of the proposed algorithm, and show that it outperforms the existing ones in all cases.

The rest of the paper is organized as follows. In section II the new MIMO-OFDM system model is introduced. The time domain signal detection algorithm is present in section III and in section IV, the performance of the proposed algorithm is demonstrated by simulation. Finally, section V draws the conclusion.

II. System Model

Consider a MIMO-OFDM system with P transmits antennas/ users and M receive antennas. The signal corresponding to the *i* th OFDM block from the *p* th transmit antenna/user is $\beta_{i,p}[n]$, n € {0,1,2,……., N-1}(where N is the number of sub carriers in OFDM systems), p € {1,2,…,P}. This is the so called "Frequency domain" signal. Denote the frequency domain signal vector of the ith OFDM block from the *pth* transmit antenna/user as

$$\beta_{i,p} = [\, \beta_{i,p}[0] \quad \beta_{i,p}[1] \dots \quad \beta_{i,p}[N-1]\,]' \qquad (1)$$

Where (.)' represents matrix transpose. Performing N-point IFFT on it, the so called "time domain" signal vector from the *pth* transmit antenna/user is generated as

Where

$$b_{i,p} = \mathbf{F}_N \quad \beta_{,p} \qquad (2)$$

$$b_{i,p} = [b_{i,p}[0] \;\; b_{i,p}[1] \;\; b_{i,p}[2] \;\dots\; b_{i,p}[N-1] \qquad (3)$$

and FN is the N x N IFFT matrix with the (n+1,k+1)th entery as e^j2Πnk/N)/√N, n,K€{0,1,…N-1}.It is obvious that the FFT matrix is $\mathbf{F}_N$* and $\mathbf{F}_N$ $\mathbf{F}_N$*,Where (.)*represents conjugate transpose and IN denotes the NxN identity matrix. A CP of length D is inserted into $b_{i,p}$ to generate the *ith* transmitted signal block from the *p*th transmit antenna /user, denoted by $S_{i,p}$

$$S_{i,p} = [S_{i,p}[0] \;\; S_{i,p}[1] \dots S_{i,p}[N'-1]]' \qquad (4)$$

in which N'=N+D and

$$S_{i,p}[n] = \quad b_{i,p}[n-D+N], 0<+n<=D-1$$
$$b_{i,p}[n-D], D<=N<=N'-1 \qquad (5)$$

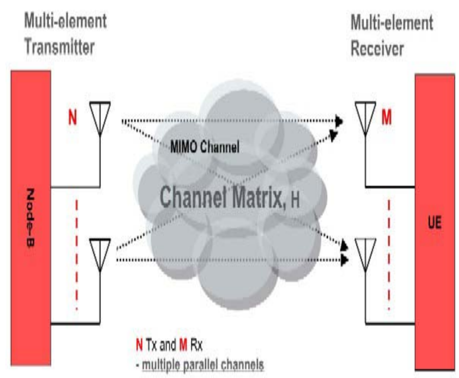


Fig1.MIMO-OFDM system model

The OFDM is the one of the most promising physical layer technology for high data rates wireless communication. OFDM has gained considerable attention in recent years. It has been adopted for various standards include the 802.11a Wireless Local Area Network standard. A WLAN is a flexible data communication system implemented as an extension to or as an alternative for, a wired LAN within a building or campus.

OFDM is a method that allows transmitting high data rates over extremely hostile channels at a comparable low complexity. The aim of this technique is to reduce the interferences between symbols [Inter Symbol Interference (ISI)]. Differently from satellite communication where we have one single direct path from transmitter to receiver, in the classical terrestrial broadcasting scenario we have to deal with a multi path-channel. The transmitted signal arrives at the receiver in various paths of different length. Since multiple versions of the signal interfere with each other (ISI)) it becomes very hard to extract the original information

In Frequency Division Multiplexing (FDM) system, signals from multiple transmitters are transmitted simultaneously (at the same time slot) over multiple frequencies. Each frequency range (sub-carrier) is modulated separately by different data stream and a spacing [Guard Band (GB)] is placed between sub-carriers to avoid signal overlap.

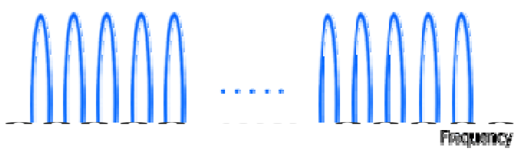


Fig2. Frequency Division Multiplexing

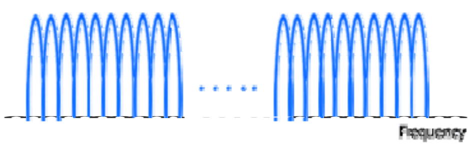


Fig3.Orthogonal Frequency Division Multiplexing

In Fig2 and Fig 3 which shows that the main difference between the FDM and OFDM. For the FDM which requires the Guard Band for the transmission. Where as the OFDM which does not requires the guard band. The OFDM technique saves the bandwidth when comparing to the FDM technique.

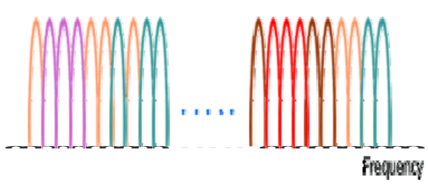


Fig4.OFDM with different sub carriers

The Fig4 shows that the different sub carriers for the OFDM. The OFDM spread-spectrum scheme is used for many broadly used applications, including, DVB, and Digital Audio Broadcasting (DAB) in Europe, Asynchronous Digital Subscriber Line (ADSL) Modems, and Wire less networking worldwide (IEEE 802.11a/g).

The Fig 5 shows that the OFDM modulation with different sub carrier .To the best knowledge of the authors, two indirect algorithms (which require estimating the channel matrix before signal detection) have been proposed for detecting the signals in this case. The fist one is a Frequency-domain algorithm [15], which applies the conventional detection algorithm for MIMO systems to each sub carrier after modelling the smoothed per sub carriers received signal similarly to the smoothed received signal of a MIMO system.

The second one is a Time domain algorithm [20], in which an equalizer is inserted to reduce the MIMO channels to ones with channel length shorter than or equal to the CP length. The general signal detection algorithm for MIMO-OFDM systems [17] is then applied. Unfortunately, both algorithms involve estimation of the channel matrix.

The channel matrix, which requires that the channel length estimation followed by channel coefficient estimation. In general, channel length estimated using information theoretic criteria such as Akaike's information criterion (AIC) or Maximum Description Length (MDL) [18] which are highly complex and computationally intensive. In addition, accurate channel length estimation error is difficult to achieve in practice and estimation error usually occurs, which will degrade the system performance. As for channel coefficient estimation, it is obvious that at lease (1+L) P (P is the number of transmit antennas/user in MIMO OFDM systems. And L is the maximum channel length) pilot symbols are required. The number of pilot symbols required increases linearly with the channel length L, thereby reducing the transmission efficiency when the channel length is large.

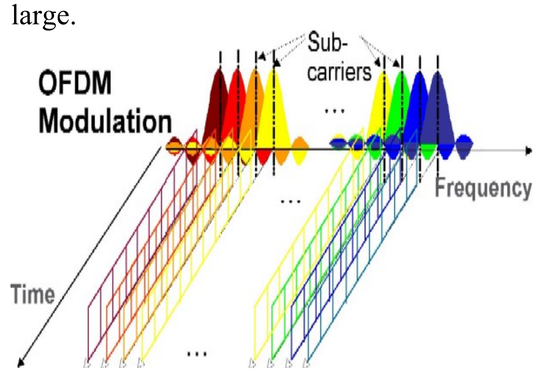


Fig5. MIMO OFDM system transmissions with sub carriers

Equalizer

Equalization (EQ) filter is a filter, usually adjustable, chiefly meant to compensate for the unequal frequency response of some other signal processing circuit or system.

An EQ filter typically allows the user to adjust one or more parameters that determine the overall shape of the filter's transfer function. It is generally used to improve the fidelity of sound, to emphasize certain instruments, to remove undesired noises, or to create completely new and different sounds.

Cyclic prefix

Cyclic Prefixes are used in OFDM in order to combat multi path by making channel estimation easy. As an example, consider an OFDM system which has N sub carriers. The OFDM symbol is constructed by taking the Inverse Discrete Fourier Transform of the message symbol, followed by a cyclic prefixing.

III Time Domain Signal Detection

In this section, a Time Domain signal detection algorithm based on SOS is proposed for MIMO OFDM systems over frequency selective fading channels.

A1) Signals from different transmit antennas/users are statistically independent, and signals from each transmit antenna/user at different sub carriers are independent with zero mean and unit variance. It implies that each transmit antenna/user modulates all sub carriers with equal power. This situation arises in spatial multiplexing and spatial multiple access systems as independent data streams are transmitted over different antennas and different sub carriers. Note that this system is different from orthogonal frequency division multiple access (OFDMA) systems where each transmit antenna/user modulates only a portion of the sub carriers. The autocorrelation matrix of the signals before IFFT is, therefore

$$Rc= E \{Ci \ Ci\}= I_{2N}P \qquad (6)$$

Where E {.} is the expectation operator.

A2) The noise components are independently identically distributed (i.i.d.) and independent of the signals from all transmit antennas/users.

A3) The MN′x (L+N′) P matrix H is of full column rank after removing all-zero columns, which means the nonzero columns are independent. This is a sufficient condition for detecting the signals based on SOS [23]. In order to meet this condition, the number of receive antennas, must be chosen to satisfy, so that there are more rows than columns. In most cases, when the number of receive antennas is chosen equal to the number of transmit antennas/users plus one, the above inequality will be satisfied. Under this assumption, the matrix has the property

$$H^* (HH^*)^{\#} H = A (N' + L) P \qquad (7)$$

Where (.) # represents pseudo inverse and A (N'+L) P is an (N'+L) PX (N'+L) P matrix with one along the major diagonal except the rows corresponding to the all zero columns except the rows corresponding to the all zero columns of H, which is equal to zero. In other words, A (N'+L) P is an (N'+L) PX (N'+L) P identify matrix with all zero rows corresponding to the all zero columns of H.

Channel estimation

The two basic 1D channel estimations are block-type pilot channel estimation and comb-type pilot channel estimation, in which the pilots are inserted in the frequency direction and in the time direction, respectively. The estimations for the block-type pilot arrangement can be based on Least Square (LS), Minimum Mean-Square Error (MMSE), and modified MMSE.

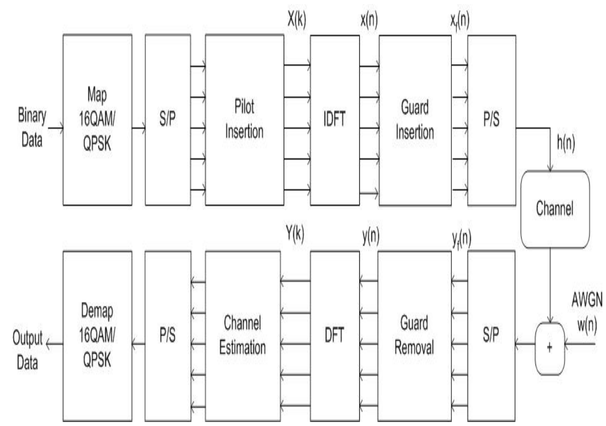


Fig.6. Channel matrix estimation

The estimations for the comb-type pilot arrangement include the LS estimator with 1D interpolation, the Maximum Likelihood (ML) estimator, and the Parametric Channel Modelling-Based (PCMB) estimator. The Fig6 shows that the channel matrix estimation for the MIMO OFDM systems.

For the channel estimation was transmitting using with Discrete Fourier Transform (DFT) and the receiving using with the Inverse Discrete Fourier Transform (IDFT). In the proposed algorithm, only 2P (P transmitted antennas /users in the MIMO-OFDM system) columns of the channel matrix need to be estimated and channel length estimation is unnecessary, which is an advantage over an existing algorithms.

IV Simulation Results

In addition, the proposed algorithm is applicable for irrespective of whether the channel length is shorter than, equal to or longer than the CP length. Simulation results verify the effectiveness of the proposed algorithm and shows that it out performs the existing one in all cases.

A ***The case where the channel length is shorter than or equal to the CP length: L. ≤ D***

In this case where the channel length is shorter than or equal to the CP length $L \leq D$ .In this case, all sub carriers are orthogonal to each other and there is no IBI. The conventional signal detection algorithms are also implemented for comparison. Note that the conventional algorithm does the FFT in the receiver to transform the frequency selective channels into flat fading channels and then performs parallel signal detection on each sub carrier with P OFDM block pilots. In the MMSE algorithm the channel coefficients are estimated using maximum likelihood method with two consecutive OFDM block pilots. The BER performance of various algorithms under consideration for L = 14 (L < D) and L = 16 (L = D) are shown in Fig6 and Fig 7 respectively. It is obvious that the proposed algorithm performs substantially better than the conventional algorithm and the MMSE algorithm over the range of SNR considered

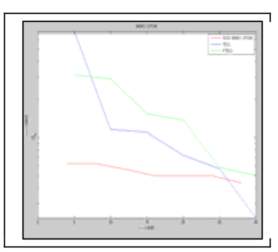


Fig 7.The channel length L= 14

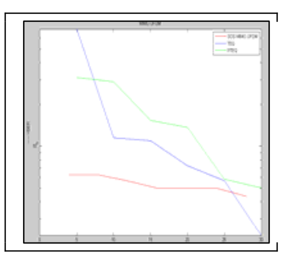


Fig8. The channel length L= 16

B ***The case whether the channel length is longer than the CP length: L > D***

In this case, the orthogonal between all sub carriers is destroyed and IBI occurs. Two indirect signal detection algorithms with exact knowledge of the channel length and coefficients and the MMSE algorithm are implemented for comparisons. Fig 9 and Fig 10 shows that the performance of various algorithms for L = 18 and L = 20 respectively for the MIMO OFDM system.

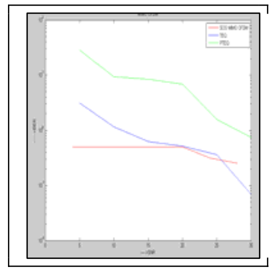


Fig.9 The channel length L= 18

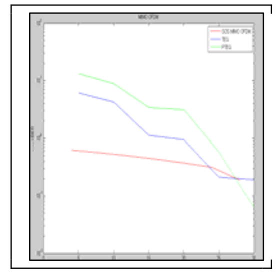


Fig10. The channel length L= 20

The different criteria for the choice of the estimation scheme were efficiency in the computation, efficiency in the estimation, accuracy in the results.

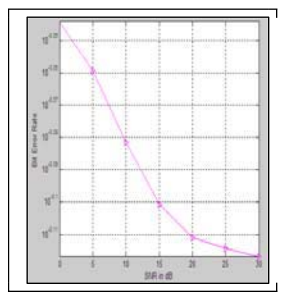


Fig.11 conventional MIMO OFDM system

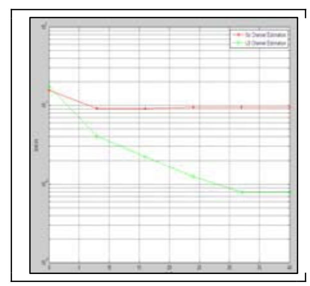
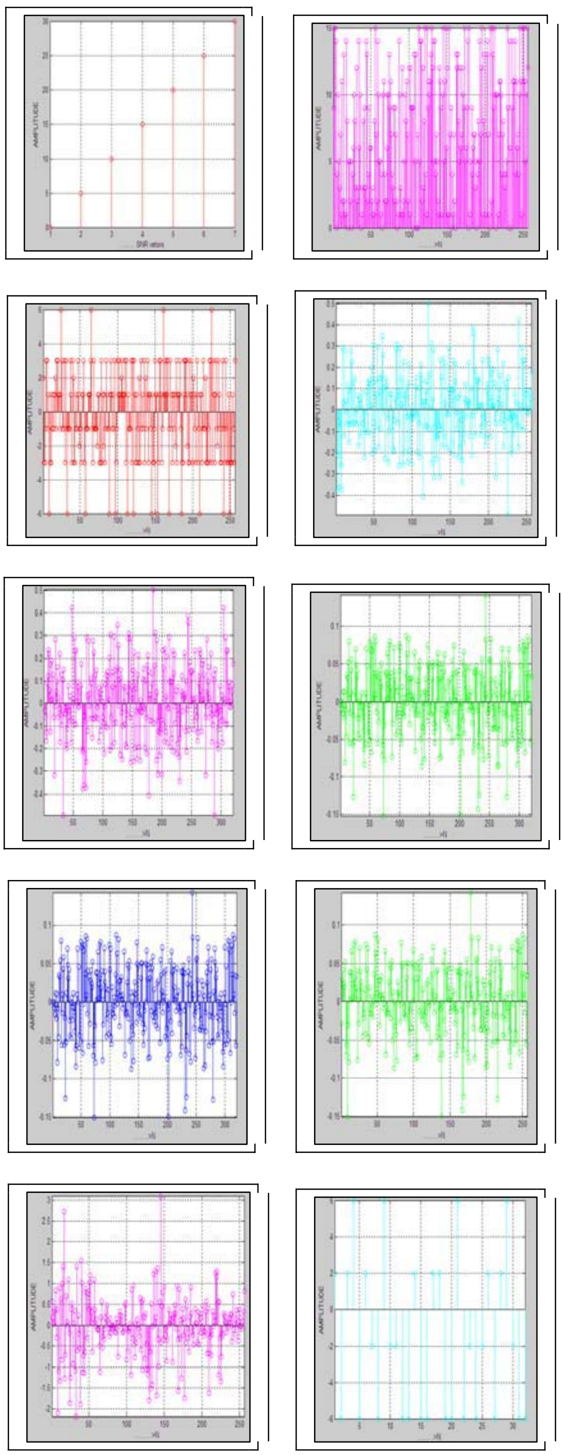
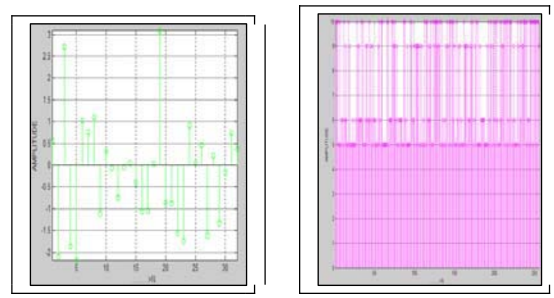


Fig12 Channel Estimation simulation

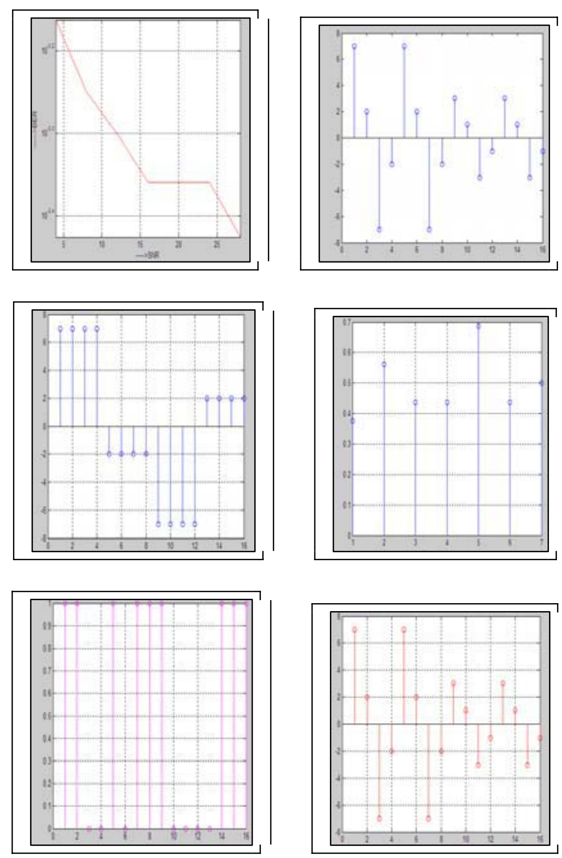
This result shows the combo pilot with channel estimation and without channel estimation. Fig12 shows that the Red colour specifies that with out channel estimation performance and the green colour specifies that the with channel estimation for the MIMO OFDM systems.

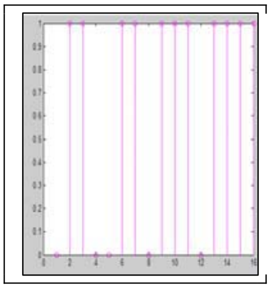
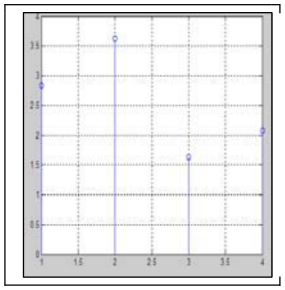
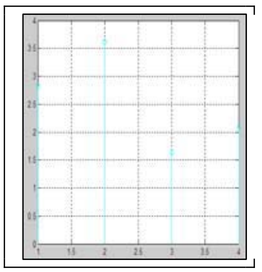
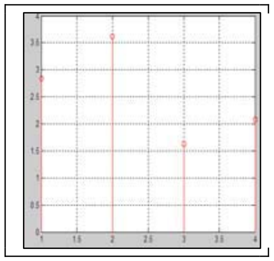
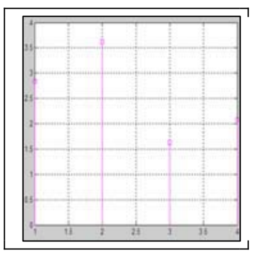
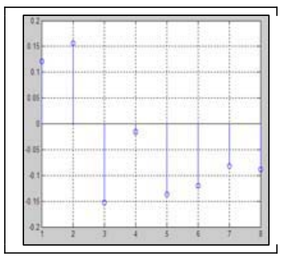
Conventional MIMO OFDM System Simulation results





Time Domain Signal Detection based on Second Order Statistics for MIMO OFDM Systems Simulation Results



The simulation results for the conventional MIMO OFDM system and the tine domain signal detection for the MIMO OFDM systems are to be simulated by using software simulation and the simulated results are to be shown on the above figures. The transmitted data bits and the received data at the receiver are too simulated. And during the transmission some pilots of the carriers are to be inserted. Initially we are assuming the bit error rate is zero and during the transmission what ever the loss can be observed. This time domain signal detection can provide the better way of communication than the other signal detection schemes. The proposed algorithm is applicable for the irrespective of whether the channel length greater than, small or equal the cyclic prefix length.

C .Comparison

To illustrate the impact of the channel length and the CP length on the proposed algorithm, the performance for L=14, 16, 17, 18, 20 cases are shown Fig.7-10. It is obvious that the performance is only slightly degraded when the channel length increases from 14 (L< D) to 20 (L > D). It demonstrates that the channel and CP lengths have insignificant effect on the proposed algorithm. It also verifies that the proposed algorithm is applicable irrespective of whether the channel length is shorter than, equal to or longer than the CP length.

V. Conclusion

A Time domain signal detection algorithm for MIMO OFDM systems has been proposed in this paper. The system model in which *i*th received OFDM block is left shifted by J samples is produced. Based on this an equalizer has been designed to cancel the most of the ISI using SOS of the received signal before signal detection. The combo pilot channel estimation has been simulated. Simulation results verify that the proposed algorithm out performs the existing one in all cases.

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