Different Types of Channel Estimation Techniques Used in MIMO-OFDM for Effective Communication Systems

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***Abstract*- A Modern wireless broadband system of MIMO-OFDM (multiple input multiple output- orthogonal frequency division multiplexing) is more popular because of good data transmission rate and its robustness against multipath fading & good spectral efficiency. This system provides reliable communication & wide coverage. A main challenge to MIMO-OFDM system is retrieval of the channel state information (CSI)accurately and synchronization between the transmitter & receiver. The channel state information is retrieved with the help of various f estimation algorithms such as training based, blind and semi blind channel Estimation. This paper describes the basic introduction of OFDM, MIMO-OFDM system and explains the different channel estimation algorithms, optimization techniques and their utilization in MIMO system for 4G wireless mobile communication systems.**

Keywords: Channel Estimation, Channel State information, LS Estimation, MMSE Estimation, MIMO-OFDM, Pilot Carriers, Mean Square Error, Spectral Efficiency.

INTRODUCTION

Fourth Generation Mobile system (4G) has very good features than previous generation networks such as 2G & 3G.Data transmission speed is very high when compared with previous generation mobile systems. It can fully supports multimedia services with extreme quality, audio, video files, wireless internet and other broadband services with superior quality. This technology provides the user to select any desired service with more freedom & flexibility Mobile communication systems transmit information by changing the amplitude or phase of radio waves. In the receiving side of mobile system, amplitude or phase can vary widely. This causes degradation in the quality of system since the performance of receiver is highly dependent on the accuracy of estimated instantaneous channel.

In a wireless link, channel state information (CSI) provides the known channel properties of the link. It provides the detail of signal propagation between transmitter and the receiver and tells about the effects of scattering, fading. The CSI can incorporate current channel conditions with transmission data for achieving reliable communication. This CSI should be estimated at the receiver and fed back to the transmitter. The channel state information can be obtained through different types of channel estimation algorithms. This estimation can be done with a set of well- known sequence of unique bits for a particular transmitter and the same can be repeated in every transmission burst. Thus the channel estimator estimates the channel impulse response for each burst separately from the well-known transmitted bits and corresponding received samples. This paper describes the fundamentals of MIMO-OFDM system and study of various channel estimation techniques and their performance.

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING(OFDM)

A. Overview of OFDM

Orthogonal Frequency-Division Multiplexing (OFDM) is a type of Frequency Division Multiplexing (FDM) method which can be used as a digital multi-carrier modulation technique. The unique property of the OFDM is orthogonality among the subcarriers, which are obtained by splitting the carrier into closely spaced orthogonal subcarriers or channels.Each subcarrier is modulated by digital modulation techniques such as quadrature amplitude modulation (QAM) or Quadrature phase- shift keying (QPSK) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. The Modulator outputs are combined and the resulting signal is transmitted.

In OFDM the large data stream to be transmitted is divided into parallel data streams. These data streams are fed to the orthogonal carriers at lower rate. Each subcarrier is modulated by using any one of the digital modulation schemes such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). The data rate for each channel is low compared to the conventional data rate for a single-carrier modulation. However the overall data rate is superior or comparable to the single-carrier modulation. Hence this scheme finds it’s applications in most of the modern wireless broadcasting systems namely 802.11n (WIFI), WiMaX, LTE and Ultra Wide Band (UWB) systems.

B. Features

In OFDM, the sub-carriers are orthogonal to each other. It avoids the interference between the sub- channels and hence no need of guard bands. Therefore the design of both the transmitter and receiver becomes easy Unlike conventional FDM, a separate filter is not necessary for each sub-channel.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

The orthogonally also allows high spectral efficiency. But OFDM requires accurate frequency synchronization between the receiver and the transmitter it is easier to transmit a large number of low-rate data streams in parallel instead of a single high-rate stream. It is easy to insert a guard interval between the OFDM symbols if the symbol duration is high. By this way, the inter symbol interference is eliminated. The guard interval also eliminates the necessity of pulse-shaping filter.

C. Mathematical Representation

If symbols to be transmitted are X_k, k=0,1,..,N-1. The OFDM symbols are placed at a frequency spacing of fs, to keep orthogonality among the subcarriers.
Where,

$$fs=1/\ (NTs)$$

Ts= sampling interval

The OFDM signal transmitted through Kth subcarrier is given by

$$x_n=\sum_{k=0}^{N-1} \quad X_K e3.14jnk \div N$$

X_K- Data Symbols
N- Number of Subcarriers
T- OFDM Symbol Time

MIMO-OFDM SYSTEM

In MIMO systems multiple antennas are used at both ends of the transmitter and receiver. Usage of MIMO-OFDM systems in modern wireless communication systems provides increased system capacity and coverage with robustness against multipath fading. Because of the unique properties of the MIMO and OFDM systems, these systems are used in high-speed wireless communication systems. A simple MIMO-OFDM system with P transmit antennas and Q receive antennas is shown in Fig. 1. MIMO can be sub-divided into three main parts pre-coding, spatial multiplexing and diversity coding respectively. Precoding is one of the multi-stream beamforming techniques employed at the transmitter. In this method same type of signals are transmitted with weighted gains from each of the transmitting antennas in order to maximize the input signal power received at the receiver. It also reduces the multipath fading effect but, it requires CSI at the transmitter.

Spatial multiplexing requires antenna configuration of the MIMO system. In this, a high data rate signal is split into a number of low data rate signals and each stream is transmitted using different antennas operating at the same frequency. At the receiver these signal arrive with different spatial signatures and it can easily separate these data stream into parallel channel. The spatial multiplexing technique increases the signal to noise ratio (SNR) and the system capacity. It can be used with or without the knowledge about the CSI at the transmitter.

Diversity coding is used to improve the signal received at the receiver without knowing the CSI. In this technique the single data stream is transmitted by using space-time coding with full or near orthogonality from each transmitting antenna. Diversity coding exploits the independent fading in multiple antenna links to improve the signal power. Spatial multiplexing techniques make the design of the receivers very complex. Therefore it is usually combined with Orthogonal Frequency-Division Multiplexing (OFDM) to combat the problems created by multi-path fading.

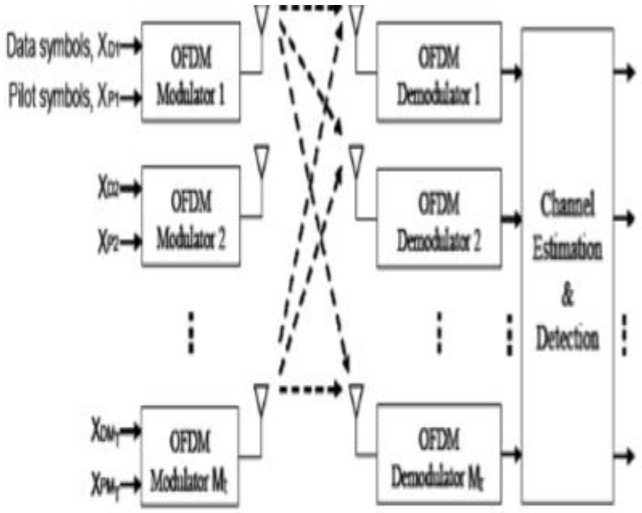

Fig.1 MIMO-OFDM System Model

A. Mathematical Description

A simple MIMO system can be modeled as

$$y=Hx+n$$

Where x and y are the transmit vector and receive vectors,H and n are the channel matrix and the noise vectors respectively.

B. Channel Estimation

In a wireless communication link, channel state information (CSI) provides the known channel properties of the link. The CSI should be estimated at the receiver and usually fed back to the transmitter. Therefore, the transmitter and receiver can have different CSI. The Channel State information may be instantaneous or statistical. In Instantaneous CSI, the current channel conditions are known, which can be viewed by knowing the impulse response of the transmitted sequence. But Statistical CSI contains the statistical characteristics such as fading distribution, channel gain, spatial correlation etc. The CSI acquisition is practically limited by how fast the channel conditions are changing. In fast fading systems statistical CSI is reasonable where channel conditions vary with a period less than the symbol time. But, in slow fading systems instantaneous CSI can be estimated with reasonable accuracy. So channel estimation technique is introduced to improve accuracy of the received signal. The radio channels in mobile communication systems are usually multipath fading channels, which are causing inter symbol interference (ISI) in the received signal. To remove ISI from the signal, several detection algorithms are used at the receiver side. These detectors should have the knowledge on channel impulse response (CIR) which can be provided by separate channel estimator.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 07, July-2018

C. Classification of Channel Estimation Techniques

Basic classification of channel estimation algorithm is shown in Fig 2. They are training based, blind channel estimation and semi-blind channel estimation. The training based channel estimation can be carried out by either block type pilots or comb type pilots along with the data symbols. In block type pilot estimation, one specific symbol full of pilot subcarriers is transmitted periodically as in Fig 3(a). This estimation is suitable for slow fading channels. But, in comb type pilot estimation pilot tones are inserted into each OFDM symbol with a specific period of frequency bins as shown in Fig. 3(b). This type of channel estimation is very much suitable where the changes even in one OFDM block. The blind channel estimation is carried out by evaluating the statistical information of the channel and particular properties of the transmitted signals. This blind channel estimation has no overhead loss and it is only suitable for slowly time-varying channels. But in training based channel estimation, training symbols or pilot tones that are known to the receiver, are multiplexed along with the data stream for channel estimation. The Semi-blind channel estimation algorithm is a hybrid combination of blind channel estimation and training based channel estimation which utilizes pilot carriers and other natural constraints to perform channel estimation.

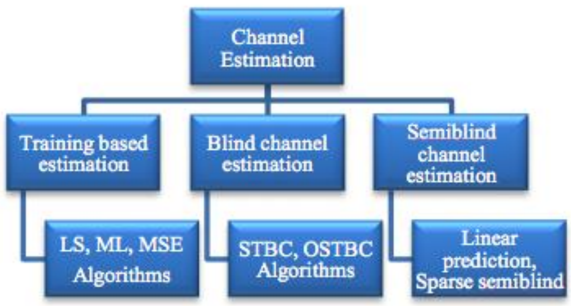

Fig.2 Classification of Channel Estimation Algorithm

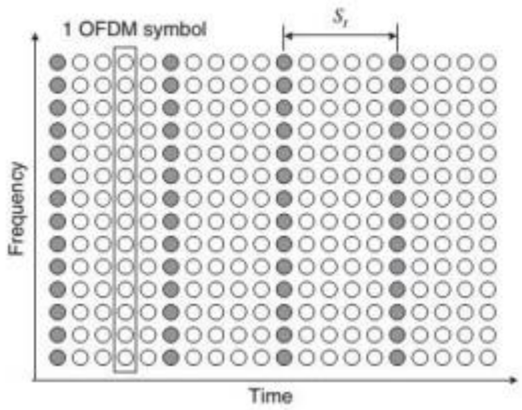

Fig.3(a)- Block Type Pilot

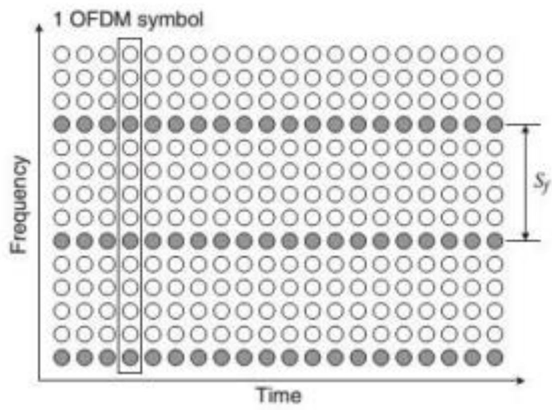

Fig. 3(b)- Comb Type Pilot

CHANNEL ESTIMATION FOR MIMO-OFDM LTE SYSTEMS

A. Training Based Channel Estimation Techniques

Various channel estimation and optimization techniques are proposed [1]-[5], [10] and [11].

W Hardjawana, R Li, B Vucetic and Y Li in [1] proposed a novel pilot- aided iterative receiver with joint ICI cancellation and decoding algorithm, based on pilot symbols and iterative soft-estimate of data symbols. The channel can be estimated using time domain interpolation and least square (LS) methods. Soft-estimate for data symbols are obtained by a maximum-a-posterior (MAP) decoder and improved subsequently using iterative process.

In [2] an Iterative channel estimation and inter carrier interference (ICI) cancellation method for highly mobile users in long-term evolution (LTE) systems is proposed. This algorithm estimates the wireless channel by using pilot symbols, estimates of the data symbols, and Doppler spread information at the receiver. The channel estimates are obtained by employing a least-square (LS) method, a simplified parallel interference cancellation (PIC) scheme coupled with decision statistical combining (DSC) are used to cancel the ICI and to improve data symbol detection.

In [3] MM Rana and MK Hosain proposed a normalized least mean (NLMS) square and recursive least squares (RLS) adaptive channel estimator for MIMO-OFDM systems. These channel estimation (CE) methods uses adaptive estimator which are able to update parameters of the estimator continuously, so that the knowledge of channel and noise statistics are not necessary. This NLMS/RLS CE algorithm requires knowledge of the received signal only. The simulation results show that the RLS CE algorithm provides faster convergence rate and good performance compared to NLMS CE method.

The performance of LS and LMMSE channel estimation techniques for LTE Downlink Systems is analyzed in [4]. Here a 2x2 LTE Downlink system is considered, the estimator's performance is evaluated in terms of Mean Square Error (MSE) and Bit Error Rate (BER). This method concentrates on the channel length parameter in comparison with the cyclic prefix (CP) inserted at the beginning of each OFDM symbol, which is usually equal to or longer than the channel length in order to suppress ICI and ISI. However, the CP length can be shorter than the channel length because of channel behavior. The simulation results show that the LMMSE outperforms the LSE, when the CP length is smaller than the channel length. In the other case, LMMSE continue its performance only for low SNR values and begins to lose its performance for higher SNR values. On the other hand, LS shows better performance than LMMSE in this range of SNR values.

In [5] Channel estimation algorithms and their implementations for mobile receivers are considered. The 3GPP long term evolution (LTE) based pilot structure is used as a benchmark in a MIMO-OFDM receiver. The decision directed (DD) space alternating generalized expectation-maximization (SAGE) algorithm is used to improve the performance from that of the pilot symbol based least-squares (LS) channel estimator. The performance is improved with high user velocities, where the pilot symbol density is not sufficient. Minimum mean square error (MMSE) filtering is also used in estimating the channel in between pilot symbols. The pilot overhead can be reduced to a third of the LTE pilot overhead with DD channel estimation, obtaining a ten percent increase in data throughput and spectral efficiency.

In order to reduce complexity and take advantage of “null” sub-carriers, MMSE based iterative channel estimation algorithm is proposed in [10]. A compensation process is proposed to simplify the traditional iterative MMSE channel estimator. After this iterative compensated MMSE channel estimation in frequency domain, a simple “linear interpolation” in time domain is performed to obtain channel estimates over all OFDM symbols. Simulation results show that the IC-MMSE channel estimation algorithm has good performances which approach the performance with perfect channel state information in both SIMO and MIMO transmission modes.

In [11], an improved DCT based channel estimation with very low complexity is proposed and evaluated in IEEE802.11n and 3GPP/LTE MIMO OFDM systems. The whole DCT window is divided into R small overlapping blocks where the length of these blocks is a power of 2. The performance is improved because the noise component is averaged on a larger number of subcarriers.

B. Blind Channel Estimation Techniques

Most of the existing blind and semi blind methods for MIMO OFDM channel estimation, except for several algorithms that are proposed for orthogonal space–time-coded systems are based on the second-order statistics of a long vector, whose size is equal to or larger than the number of sub carriers Enhancement of a blind channel estimator based on a subspace approach in a MIMO OFDM for a high mobility scenario is proposed in [6]. The simulations results have demonstrated the effectiveness of the approach for a 16 QAM modulation scheme and had been evaluated in term of bit error rate BER and mean square error MSE versus the signal to noise ratio SNR.

C. Semi Blind Channel Estimation Technique

The Semi blind channel estimation algorithms, exploit the second-order stationary statistics, correlative coding, and other properties, normally have better spectral efficiency With a small number of training symbols. These methods have been proposed to estimate the channel ambiguity matrix in MIMO-OFDM systems [7], [8].

An optimized channel estimation algorithm for Multipath MIMO-OFDM Systems has been proposed in [9]. This method has a better estimation performance than the compressive sampling matching pursuit sparse channel estimation method (CoSaMP-SCE). Furthermore, the proposed method does not need to use the sparsity information, while the CoSaMP-SCE requires it.

CONCLUSION

In this paper,the basic concepts of Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output(MIMO) systems are discussed. The various channel estimation techniques such as training based,blind channel,semiblind channel based algoritms and their performance are also discussed.Also different optimization techniques such as particle swarm optimization,evolutionary programming is Reviewed to optimize LS & MMSE algorithms.

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