International Journal of Engineering Research in Electronic and Communication Engineering (IJERECE) Vol 3, Issue 5, May 2016

Channel Estimation Techniques in MIMO-OFDM

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Abstract: **This paper presents different channel estimation techniques in MIMO-OFDM. The combination of MIMO with OFDM increases the bit rate as well as capacity. This is a survey on channel estimation. A main challenge in MIMO-OFDM system is retrieval of channel state information (CSI) accurately and the synchronization between the transmitter and receiver. The CSI is retrieved with the help of different types of estimation algorithms such as training based, blind and semi blind channel estimation. This paper focuses the basic introduction of OFDM, MIMO-OFDM system and explain different channel estimation algorithms, optimization techniques and their utilization in MIMO systems for 4G wireless mobile communication systems.**

Key terms- **Channel estimation, CSI, MIMO-OFDM**

I. INTRODUCTION

The features of fourth generation (4G) mobile system has very well than previous generation networks such as 2G and 3G. Key challenge faced by future communication system is to provide high data rate with high quality of service (QoS). Comparing to 2G and 3G the data transmission speed is very high in 4G. It can supports multimedia services with extreme quality, audio, video files, internet and other broadband services with superior quality. It provides user to select any desired services with more freedom and flexibility.

Mobile communication systems transmit information by changing their amplitude or phase of radio waves. At the receiver side of mobile system, amplitude or phase can vary widely. This leads to 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 CSI 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 performances.

II. ORTHOGONAL FREQUENY DIVISION MULTIPLEXING

Orthogonal frequency-division multiplexing (OFDM) is a type of frequency-Orthogonal frequency-division multiplexing (OFDM) is a type of frequency-division multiplexing (FDM) and can be used as a digital multi-carrier modulation technique. Usually large number of closely-spaced orthogonal sub-carriers is used to carry data [1]. The data is spited into various parallel data streams (or channels), one for each sub-carrier. 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. It could be up converted and amplified if needed. This scheme is mostly used in various applications such as digital TV & audio broadcasting, wireless LANs, Wi-Fi, WiMAX, LTE systems [1,3]

In OFDM, each sub-carrier is orthogonal to each other. It avoids the inter symbol interference (ICI), inter channel interference (ICI) and hence no need of guard bands. Therefore the design of both the transmitter and receiver becomes more easy .Unlike conventional FDM, a separate filter is not necessary for each sub-channel.

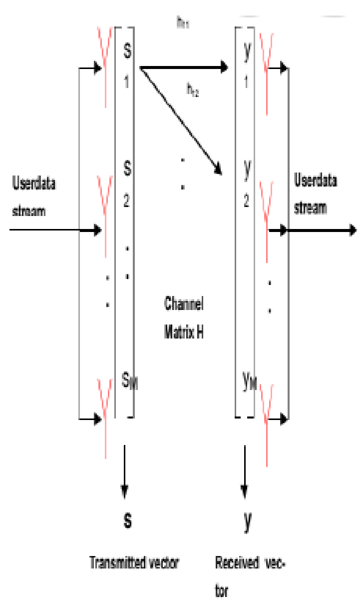
Orthogonally also allows high spectral efficiency. But OFDM requires accurate frequency synchronization between the receiver and the transmitter [9].

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 and by this way, the inter symbol interference is eliminated. The guard interval also eliminates the need of pulse-shaping filter [7].

III. MIMO-OFDM

MIMO refers to multiple input multiple output system. That means more than one antennas are used at the transmitter and receiver side. For this the basic system is a 2×2 system. It is a modern wireless broad band technology which has great capability of high rate data transmission and its robustness against multi-path fading and other channel impairments. In general, the MIMO-OFDM transmitter has NT parallel transmission paths which are very similar to the single antenna OFDM system, each branch performing serial-to-parallel conversion, pilot insertion, N-point IDFT, cyclic extension and signals are up-converted to RF and transmitted. Encoding and modulation can also be done per branch in channel [1].

At the receiver end, the CP is removed and N-point DFT is performed for each receiver branch. Then using Space Time decoding transmitted symbol from each transmitted is combined. To obtain the output signal demodulation and decoding operations are performed. A simple MIMO system with two transmit antennas and two receiving antennas shown here.



MIMO can be sub-divided into three main parts such as preceding, spatial multiplexing and diversity coding. Preceding is one of the multi-stream beam forming technique which is employed at the transmitter. In beam forming, the same type of signal is emitted from each one of the transmit antennas with appropriate phase weighting such that the maximum received input signal power at the receiver. This technique increases the received signal gain, by employing signals emitted from multiple antennas and also reduces the multipath fading effects. It requires exact knowledge of channel state information (CSI) at the transmitter. Spatial multiplexing requires MIMO antenna configuration [5].

In spatial multiplexing, a high rate signal is splited into several low rate data streams and each stream is transmitted with the help of different transmit antennas which are having the same frequency. If these signals arrive at the receiver antenna array with different spatial signatures, the receiver can easily separate this stream of data into parallel channels. It is one of the excellent technique to increase the channel capacity and improves high signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by less number of transmitting antennas at the transmitter or at the receiver. Spatial multiplexing can be used with or without the knowledge of transmitter [2].

Diversity Coding techniques are used when there is no channel knowledge at the transmitter. In diversity coding a single data stream is transmitted with a coding technique called as space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beam forming or array gain from diversity coding. Spatial multiplexing can also be combined with precoding when the channel is known at the transmitter or combined with diversity coding when decoding reliability is in trade-off [5].

Spatial multiplexing techniques make the receivers very complex. Therefore it is usually combined with orthogonal frequency-division multiplexing (OFDM) or with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by multi-path channel are handled efficiently.

Mathematically a MIMO system can be modeled as

$$Y=Hx+n$$

Where x and y are the transmit and receive vectors respectively, and H and n are the channel matrix and noise vector respectively. Ideally, the channel matrix is known perfectly. Due to channel estimation errors, it may vary. For elimination of ISI the guard time interval should be more than the expected largest delay spread of a multipath channel. The transmitted signal will be the convolved with the channel to get the received signal. Assuming that the channel is static during an OFDM block, at the receiver side after removing the CP, the FFT output as the demodulated received signal [1,3].

IV. CHANNEL ESTIMATION

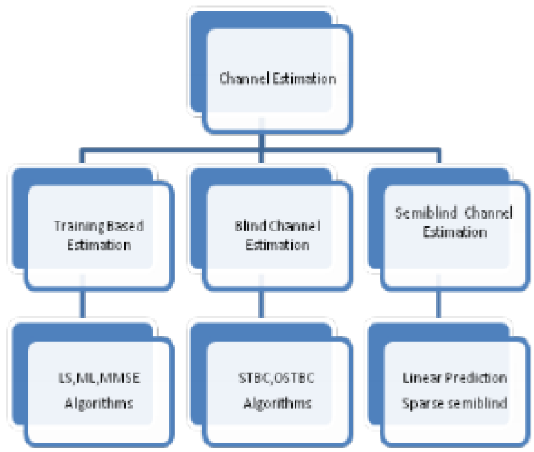
In a wireless communication link, channel state information (CSI) provides the known channel properties of the link. This CSI should be estimated at the receiver and usually fed back to the transmitter. Therefore, the transmitter and receiver can have different CSI. The Channel State information may 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 [1].

In fast fading systems where channel conditions vary rapidly under the transmission of a single information symbol, only statistical CSI is reasonable. 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 [3]. The radio channels in mobile communication systems are usually multi path fading channels, which are causing inter symbol interference (ISI) in the received signal. To remove ISI from the signal, much kind of 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 estimation [4].

In an OFDM system, the transmitter modulates the message bit sequence into PSK/QAM symbols, performs IFFT on the symbols to convert them into time - domain signals, and sends them out through a (wireless) channel. The received signal is usually distorted by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver. Each subcarrier can be regarded as an independent channel, as long as no ICI (Inter -Carrier Interference) occurs, and thus preserving the orthogonality among subcarriers. The orthogonality allows each subcarrier component of the received signal to be expressed as the product of the transmitted signal and channel frequency response at the subcarrier. Thus, the transmitted signal can be recovered by estimating the channel response just at each subcarrier. In general, the channel can be estimated by using a preamble or pilot symbols known to both transmitter and receiver, which employ various interpolation techniques to estimate the channel response of the subcarriers between pilot tones. In general, data signal as well as training signal, or both, can be used for channel estimation [10]

Classification of Channel Estimation:

Basically channel estimation algorithms are classified as training based, blind channel estimation and semi blind channel estimation [1].



The training-based channel estimation can be performed by either block type pilots or comb type pilots. In block type pilot estimation, pilot tones are inserted into all frequency bins within the periodic intervals of OFDM blocks. 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. This type of channel estimation is very much suitable where the changes even in one OFDM block [7].

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 [7,8 9].

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 [1].

V. A PILOT STRUCTURE

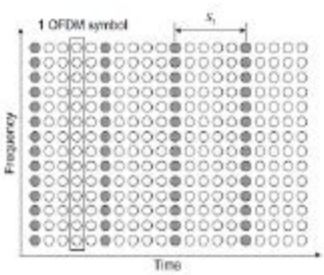
Depending on the arrangement of pilots, three different types of pilot structures are considered: block type, comb type, and lattice type

a. Block Type

In this, OFDM symbols with pilots at all subcarriers (referred to as pilot symbols herein) are transmitted periodically for channel estimation. Using these pilots, a time-domain interpolation is performed to estimate the channel along the time axis. As the coherence time is given in an inverse form of the Doppler frequency $fDoppler$ in the channel, the pilot symbol period must satisfy the following inequality:

$$S_t \leq 1/\left(f_{Doppler}\right)$$

Block type pilot arrangement is shown below.



b. Comb Type

In this, every OFDM symbol has pilot tones at the periodically-located subcarriers, which are used for a frequency-domain interpolation to estimate the channel along the frequency axis. As the coherence bandwidth is determined by an inverse of the maximum delay spread $Smax$, the pilot symbol period must satisfy the following inequality.

$$Sf \leq 1/\left(\sigma max\right)$$

VI. CHANNEL ESTIMATION ALGORITHMS

LS Channel Estimation Method

In communication systems, channels are usually multi-path channels, which cause inter-symbol interference in the received signal. Channel estimators require the channel impulse response (CIR). The channel estimation is based on the known sequence of bits called training sequence which is unique for each transmitter. Here the known training sequence is transmitted so that the channel coefficients are obtained [1, 5, and 9].

VII. 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, semi blind channel based algorithms and their performance are also discussed.

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