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A Review on Channel Estimation Techniques for MIMO-OFDM in Wireless Systems

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ABSTRACT: Orthogonal Frequency Division Multiplexing is used to improve spectral efficiency and Multiple Input Multiple Output (MIMO) is used to improve spatial diversity in today wireless communications systems. Therefore for proper detection of all data symbols channel estimation techniques play great role to system performance. This paper provides a review of channel estimation techniques for MIMO-OFDM systems.

KEYWORDS: Multiple Input Multiple Output (MIMO), MIMO-OFDM (multiple input multiple output- orthogonal frequency division multiplexing)

I.INTRODUCTION

MIMO-OFDM (multiple input multiple output- orthogonal frequency division multiplexing) 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 MIMO system, multiple numbers of transmitters at one end and multiple numbers of receivers at the other end are effectively combined to improve the channel capacity of wire-less system. This technology highly improves the spectrum efficiency, reliability of system & coverage area. A simple MIMO-OFDM system shown in figure 1.

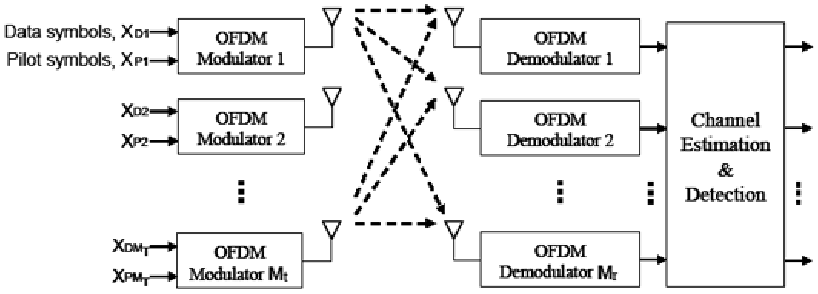


Figure.1: Block Diagram of MIMO OFDM System

II.LITERATURE REVIEW

In 2001, Rick S Blum, [15] proposed an improved spacetimecoding for multiple input and multiple outputorthogonal frequency division multiplexing using QPSKmodulation for four transmit and four receive antennas.Furthermore they showed a 4-antenna, 16 state codes that achieve an additional 2-dB improvement with lowercomplexity and a 256 state code that achieves an additional 2-dB gain. The 256-state code performed within 3db ofoutage capacity.

In 2004, Garden L. Stuber [16] discussed a number of physical layer issues relevant for the implementation ofbroadband MIMO-OFDM systems. They discussed space time coding strategies for closed loop MIMO-OFDMsystems where knowledge of the channel is available at thetransmitter. Error-correction coding was discussed with anemphasis on high rate LDPC codes. Adaptive analog beamforming techniques were discussed that can provide the bestpossible MIMO channel environment.

In 2006, Toufiqual Islam [7] presented multiuser channel estimation technique for space time block coded orthogonalfrequency division multiplexing (STBC-OFDM) systems Based on simple blocked pilot grid. The estimation of multiuser channels are based on least square (LS) andMinimum mean square estimation (MMSE) schemes. Thesimulation result shows that for a slowly faded quasi-staticchannel estimated characteristics closely agree with theactual channel characteristics. Different Doppler fadingeffects on MMSE performance are also presented.

In 2009, Y. Mlayels [7] investigate an extra processingadded to conventional LS estimation to improve itsperformance in MIMO-OFDM systems. The new techniqueproposed is based on knowledge of the power delay profile.The application of the improved estimator is useful when employing advanced MIMO adaptication techniques. Simulation results showed performance of MIMOtechniques closed to that offered by perfect channel.

In 2011, Zangjie et al. [8] presents a simulation model of MIMO-OFDM system based on STBC which built andtransmission performances under different channels areanalyzes. The simulation results shoe that the MIMO-OFDMsystem based on STBC outperforms other MIMO-OFDMsystem without STBC in BER performance.

In 2013, Andre Antonio dos Anjos [8] addressed theproblem to perform accurate channel estimation. Theypresented some channel estimation techniques that can beused in MIMO-OFDM systems that designed for diversitygain. The influence of interpolation technique on channelestimation error and MER has been analyzed. Differentchannels with different delay profiles have also beenanalyzed. A linear relationship between channel estimation error and the MER has been been proposed.

In 2014, Melli, X.Wang, K.Zang [10] analyzed the leastmean square (LMS) and Recursive least square (RLS) algorithms. They applied these two algorithms to MIMO-OFDMsystem based on space time block coding (STBC).From the simulation results it is found that the RLS is betterthan LMS algorithm. They showed the practical aspect ofanalyzed scheme in MATLAB environment.

III.SYSTEM MODEL

A generic block diagram of a basic baseband-equivalentMIMO-OFDM system is given in Fig. 2. A MIMO-OFDMsystem withN_{tx}transmit andN_{rx}receive antennas is assumed.The information bits can be coded and interleaved. The codedbits are then mapped into data symbols depending on the modulation type. Another stage of interleaving and codingcan be performed for the modulated symbols. Although thesymbols are in time domain, the data up to this point is considered to be in the frequency domain. The data is then demultiplexed for different transmitter antennas. The serial data symbols are then converted to parallel blocks, and an IFFT isapplied to these parallel blocks to obtain the time domainOFDM symbols. For the transmit antenna, tx, time domainsamples of an OFDM symbol can be obtained from frequencydomain symbols as

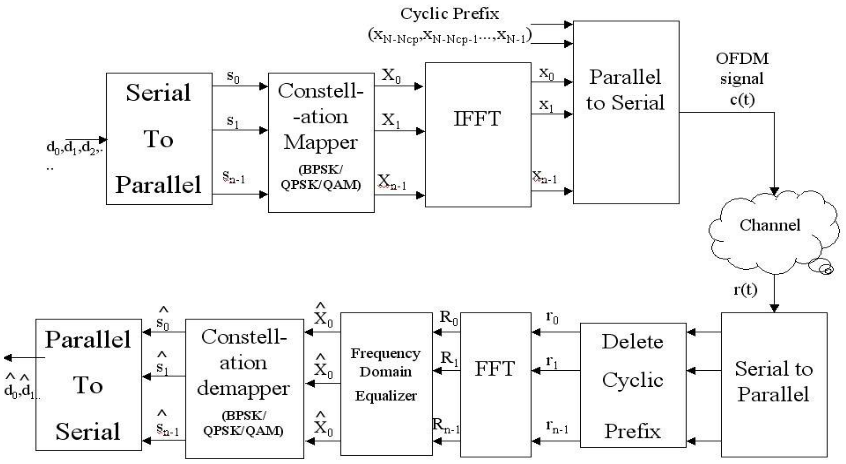


Figure.2: Simple OFDM System

$$x_{tx}[n,m] = IFFT\{X_{tx}[n,k]\} = \sum_{k=0}^{K-1} X_{tx}[n,k]e^{j2\pi mk/K}\quad 0 \le k,m \le K-1 \tag{1}$$

WhereX_{tx} [n, k] is the data at the k_{th} subcarrier of the n_{th}OFDM symbol, K is the number of subcarriers and m is the time domain sampling index.

The channel at time t is expressed as,

$$h(t,\tau) = \sum_{l=0}^{L-1} \alpha_l(t)\delta(\tau - \tau_l),$$

Where L is the number of taps, $\alpha_l$is the l_{th} complex path gain, and $\tau_l$is the corresponding path delay.
The individual paths can becorrelated, and the channel can be sparse. At time t, the CFR of the CIR is given by

$$H(t,f) = \int_{-\infty}^{+\infty} h(t,\tau)e^{-j2\pi f\tau}d\tau$$

CFR can be if proper path is found

$$H[n,k] \equiv H(nT_f, k\Delta f) = \sum_{l=0}^{L-1} h[n,l]F_K^{kl}$$

Where h [n, l] = h(nT_f, kt_s), and $F_K = e^{-2\pi j/k}$$T_f$is the symbol length including CP, Δf is the subcarrier spacing, and t_s = 1/D_f is the sample interval.
For the nth OFDM symbol,can be rewritten as

H = Fh

H is the column vector containing the channel at eachsubcarrier, F is the unitary FFT matrix, and h is the columnvector containing the CIR taps.

At the receive antenna, rx, can be formulated as

$$y_{rx}[n,m] = \sum_{tx=1}^{N_{tx}} \sum_{l=0}^{L-1} x_{tx}[n,m-l]h_{rxtx}^{m}[n,l] + i_{rx}[n,m] + w_{rx}[n,m],$$

where rx =1, …, N_{rx},
After taking FFT of the timedomain samples, the received samples in frequencydomain can be expressed as,

$$
\begin{aligned}
Y_{rx}[n,k] &= \frac{1}{K}\sum_{m=0}^{K-1} y_{rx}[n,m]e^{-j\frac{2\pi km}{K}} \\
&= \frac{1}{K}\sum_{m=0}^{K-1}\left[\sum_{tx=1}^{N_{tx}}\sum_{l=0}^{L-1} x_{tx}[n,m-l]h_{rxtx}^{m}[n,l]\right. \\
&\quad \left. + i_{rx}[n,m] + w_{rx}[n,m]\right]e^{-j\frac{2\pi km}{K}} \\
&= \sum_{tx=1}^{N_{tx}}\frac{1}{K}\sum_{m=0}^{K-1}\left[\sum_{l=0}^{L-1}\left[\sum_{k'=0}^{K-1} x_{tx}[n,k']e^{j2\pi(m-l)k'/K}\right]\right. \\
&\quad \left. h_{rxtx}^{m}[n,l]\right]e^{-j\frac{2\pi km}{K}} + I_{rx}[n,k] + W_{rx}[n,k]
\end{aligned}
$$

where $I_{rx}[n, k]$ and $W_{rx}[n, k]$ are the corresponding frequencydomain components calculated from $i_{rx}[n, m]$ and $w_{rx}[n, m]$,respectively.
for rx_{th} receive antenna and n_{th}OFDM symbol, we get

$$
\begin{aligned}
\mathbf{Y}_{rx} &= \sum_{tx-1}^{N_{tx}} \mathbf{F}\Xi_{rxtx}\mathbf{F}^{H}\mathbf{X}_{tx} + \mathbf{I}_{rx} + \mathbf{W}_{rx}, \\
&= \sum_{tx-1}^{N_{tx}} \Psi\mathbf{X}_{tx} + \mathbf{I}_{rx} + \mathbf{W}_{rx}.
\end{aligned}
$$

Here, Y_{rx} is column vector storing the received signal at each subcarrier, F is the unitary FFT matrix with entries $e^{-j2\pi mk/K}\sqrt{K}$with m and k being the row and column index and □□=**F**□$_{rxtx}$**F**^{H}, which can be considered as the equivalentchannel between each received and all the transmitted subcarriers.

X_{tx}denotes the column vector for transmitted symbols from tx_{th} transmit antenna, I_{rx} is the column vector for interferers, Wrx is the column vector for noise, and Ξ_{rxtx} is the matrix he channel taps at each m index. The entries of Ξ are given by

$$
\Xi_{rxtx} = \begin{bmatrix}
h_{rxtx}^{0}[n,0] & 0 & 0 \\
h_{rxtx}^{1}[n,1] & h_{rxtx}^{1}[n,0] & 0 \\
\vdots & \vdots & \vdots \\
h_{rxtx}^{L-1}[n,L-1] & h_{rxtx}^{L-1}[n,L-2] & 0 \\
\vdots & \vdots & \vdots \\
0 & 0 & 0
\end{bmatrix}
$$

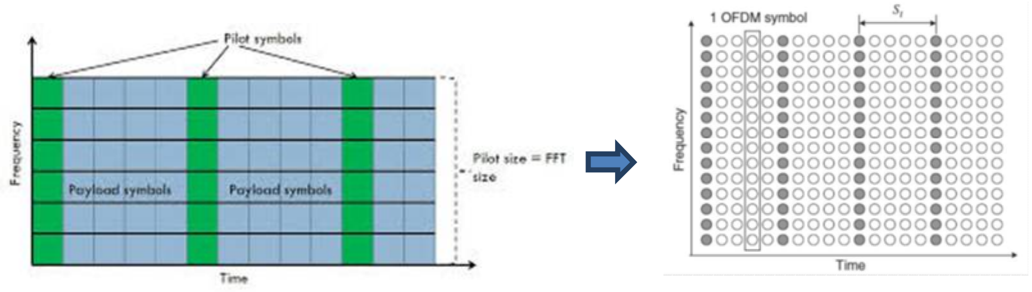
$$
\left|\begin{matrix}
\cdots & h_{rxtx}^{0}[n,2] & h_{rxtx}^{0}[n,1] \\
\cdots & h_{rxtx}^{1}[n,3] & h_{rxtx}^{1}[n,2] \\
\vdots & \vdots & \vdots \\
\cdots & 0 & 0 \\
\vdots & \vdots & \vdots \\
\cdots & h_{rxtx}^{K-1}[n,L-1] & h_{rxtx}^{K-1}[n,0]
\end{matrix}\right. .
$$

IV.CHANNEL ESTIMATION TECHNIQUES FOR MIMO-OFDM

In an MIMO-OFDM system, the transmitter modulates themessage bit sequence into QAM symbols, performsIFFT on the symbols to convert them into time-domainsignals, and sends them out through a (wireless) channel.The received signal is usually distorted by the channelcharacteristics. In order to recover the transmitted bits, thechannel effect must be estimated and compensated in thereceiver. The orthogonality allows eachsubcarrier component of the received signal to beexpressed as the product of the transmitted signal andchannel frequency response at the subcarrier. Thus, thetransmitted signal can be recovered by estimating thechannel response just at each subcarrier. In general, thechannel can be estimated by using a preamble or pilotsymbols known to both transmitter and receiver, which employ various interpolation techniques to estimate thechannel response of the subcarriers between pilot tones. Ingeneral, data signal as well as training signal, or both, canbe used for channel estimation.

MIMO-OFDM Pilot

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



Training and estimation based channel estimation

Training symbols can be used for channel estimation, usually providing a good performance. However, their transmission efficiencies are reduced due to the requiredoverhead of training symbols such as preamble or pilottones that are transmitted in addition to data symbols.The least-square (LS) and minimum-mean-square-error (MMSE) techniques are widely used for channelestimation when training symbols are available.

DFT-based channel estimation

The DFT-based channel estimation technique has been derived to improve the performance of LS or MMSE channel estimation by eliminating the effect of noise outside the maximum channel delay. Note that the maximum channel delay L must be known in advance. This technique is used for noise reduction.

Semi-blind channel estimator

Semi-blind channel estimators are another class of channel estimators that utilize not only that part of signal corresponding to the training symbols but also the part corresponding to data symbols. In particular, a semi-blind channel estimator takes {sp1, sp2, b} to generate a channel estimate.

Blind channel estimation

Using the statistical properties of received signals, the channel can be estimated without resorting to the preamble or pilot signals. Obviously, such a blind channel estimation technique has an advantage of not incurring an overhead with training signals. However, it often needs a large number of received symbols to extract statistical properties. Furthermore, their performance is usually worse than that of other conventional channel estimation techniques that employ the training signal. It consists of a filter, zero-memory nonlinear estimator, and adaptive algorithm.

Pilot based channel estimation

In the pilot mode, only few subcarriers are used for the initial estimation process. Depending on the stage where the estimation is performed, estimation techniques will be considered under time and frequency domains techniques.In frequency domain estimation techniques, as a first step, CFR for the known pilot subcarriers is estimated via (22).These LS estimates are then extrapolated to getthe channel at the non-pilot subcarriers. The process of theextrapolation can be denoted as

$$\hat{\mathbf{H}}=\mathbf{Q}\hat{\mathbf{H}}^{LS}$$

Where Q is the interpolation/extrapolation matrix. The goal ofthe estimation technique is to obtain Q with lower computationalcomplexity but at the same time is to achieve higheraccuracy for a given system. In this subsection, the calculationof matrix Q for simple interpolation techniques will be discussed.
Let A is the diagonal matrix of pilots asA=diag{ A_0 , A_1, … , A_{N-1}}, N is the number of pilots in one OFDM symbol, $\hat{\mathbf{h}}$ is the impulse response of the pilots of one OFDM symbol, and **Z**is the Channel noise.

At the receiving end signal received is written as

$$B = AF\hat{h} + Z$$

where B is the vector of output signal after OFDMdemodulation as$B=\{B_0,B_1,\ldots B_{N-1}\}^T$
F is the Fourier transfer matrix as

$$F = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}$$

Where weights of Fourier matrix is

$$W_N^{i,k} = \frac{1}{\sqrt{N}} e^{-j2\pi(\frac{ik}{N})}$$

The detection function is

$$\begin{aligned} K &= \left| B - AF\hat{h} \right|^2 \\ &= (B - AF\hat{h})^H (B - AF\hat{h}) \\ &= B^H B - B^H AF\hat{h} - A^H BF^H \hat{h}^H + A^H F^H \hat{h}^H AF\hat{h} \end{aligned}$$

For the minimization of K

$$\frac{\partial K}{\partial \hat{h}^H} = 0$$

$$= F^H A^H B + F^H A^H AF\hat{h}$$

$$= 0$$

V.CONCLUSION

A review of different channel estimation techniques hasbeen discussed. Different channel estimators such as pilotbased estimator, blind channel estimator and semi-blindchannel estimators have been discussed and it is concludedthat pilot based channel estimation is far better than others, because blind and semi-blind channel estimator usemathematical information about the transmitted data andbecome complex. Block type arrangement and comb typearrangement for pilot insertion have been reviewed andcompared. Block type arrangement is used for slow fadingchannel whereas comb type arrangement is used for fastfading channel. In block type arrangement includesalgorithms like LSE, MMSE whereas comb typearrangement includes interpolation techniques such aspiecewise constant interpolation, linearinterpolation, second order interpolation, cubic splineinterpolation and time domain interpolation techniques. Ithas been found that the performance of MMSE is muchbetter than LSE but computation is very complex whennumber of subcarrier of OFDM increases. However, applying the DFT on the estimated output of thesealgorithms the results can be improved. DFT basedchannel estimation technique allows the reduction of noisecomponent owing to operation in the transform domainand thus providing higher estimation accuracy.

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