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Review: PERFORMANCE EVALUATION OF CHANNEL ESTIMATION IN MIMO OFDM

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ABSTRACT

A multiple-input multiple-output (MIMO) communication system combined with the orthogonal frequency division multiplexing (OFDM) modulation technique can achieve reliable high data rate transmission high data rate transmission over broadband wireless channels. The data rate and spectrum efficiency of wireless mobile communications have been significantly improved over the last decade or so. Recently, the advanced systems such as 3GPP LTE and terrestrial digital TV broadcasting have been sophisticatedly developed using OFDM and CDMA technologyChannel state information for both single-input single-output (SISO) and MIMO systems is investigated in this paper. The estimation of channel at pilot frequencies with conventional Least Square (LS) and Minimum Mean Square (MMSE) estimation algorithms is carried out through Matlab simulation. The performance of MIMO OFDM and SISO OFDM are evaluated on the basis of Bit Error Rate (BER) and Mean Square Error (MSE) level. Further enhancement of performance can be achieved through maximum diversity Space Time Block Coding (STBC) and Maximum Likelihood Detection at transmission and reception ends respectively. MMSE estimation has been shown to perform much better than LS but is more complex than LS for the MIMO system using pilot carriers.

*Keywords:***Channel Estimation, MIMO-OFDM, Pilot carriers, Diversity, Spatial Multiplexing, Space time coding**

I. INTRODUCTION

During the past few years, there has been an explosion in wireless technology. This growth has opened a new dimension to future wireless communications whose ultimate goal is to provide universal personal and multimedia communication without regard to mobility or location with high data rates. To achieve such an objective, the next generation personal communication networks will need to be support a wide range of services which will include high quality voice, data, facsimile, still pictures and streaming video. These future services are likely to include applications which require high transmission rates of several Mega bits per seconds (Mbps).

The data rate and spectrum efficiency of wireless mobile communications have been significantly improved over the last decade or so. Recently, the advanced systems such as 3GPP LTE and terrestrial digital TV broadcasting have been sophisticatedly developed using OFDM and CDMA technology. In general, most mobile communication systems transmit bits of information in the radio space to the receiver. The radio channels in mobile radio systems are usually multipath fading channels, which cause inter-symbol interference (ISI) in the received signal. To remove ISI from the signal, there is a need of strong equalizer which requires knowledge on the channel impulse response [1].

Equalization techniques which can combat and/or exploit the frequency selectivity of the wireless channel are of enormous importance in the design of high data rate wireless systems. Although such techniques have been studied for over 40 years, recent developments in signal processing, coding and wireless communications suggest the need for paradigm shifts in this area.On one hand, the demonstrated efficiency of soft-input soft-output signal processing algorithms and iterative (turbo) techniques have fuelled interest in the design and development of nearly optimal joint equalization and decoding techniques. On the other hand, the popularity of MIMO communication channels, rapidly time varying channels due to high mobility, multi-user channels, multi-carrier based systems and the availability of partial or no channel state information at the transmitter and/or receiver bring new problems which require novel equalization techniques [2].Hence, there is a need for the development of novel practical, low complexity equalization techniques and for understanding their potentials and limitations when used in wireless communication systems characterized by very high data rates, high mobility and the presence of multiple antennas.In radio channels, a variety of adaptive equalizers can be used to cancel interference while providing diversity. Since the mobile fading channel is random and time varying, equalizers must track the time varying characteristics of the mobile channel, and thus are called adaptive equalizers.The general operating modes of an adaptive equalizer include training and tracking. First, a known, fixed-length training sequence is sent by the transmitter so that the receiver's equalizer may adapt to a proper setting for minimum bit error rate (BER) detection. The training sequence is typically a pseudorandom binary signal or a fixed, prescribed bit pattern. Immediately following this training sequence, the user data (which may or may not include coding bits) is sent and the adaptive equalizer at the receiver utilizes a recursive algorithm to evaluate the channel and estimate filter coefficients to compensate for the distortion created by multipath in the channel. The training sequence is designed to permit an equalizer at the receiver to acquire the proper filter coefficients in the worst possible channel conditions(e.g., fastest velocity, longest time delay spread, deepest fades, etc.) so that when the training sequence is finished, the filter coefficients are near the optimal values for reception of user data. As user data are received, the adaptive algorithm of the equalizer tracks the changing channel. As a consequence, the adaptive equalizer is continually changing its filter characteristics over time. When an equalizer has been properly trained, it is said to have converged. The time span over which an equalizer converges is a function of the equalizer algorithm, the equalizer structure, and the time rate of change of the multipath radio channel.

II. OBJECTIVES

In mobile communications systems, data transmission at high bit rates is essential for many services such as video, high quality audio and mobile integrated service digital network. When the data is transmitted at high bit rates, over mobile radio channels, the channel impulse response can extend over many symbol periods, which leads to Inter-symbol interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM) is one of the promising technology to mitigate the ISI. In an OFDM signal the bandwidth is divided into many narrow sub-channels which are transmitted in parallel. Each sub-channel is typically chosen narrow enough to eliminate the effect of delay spread. By combining OFDM with CDMA dispersive fading limitations of the cellular mobile radio environment can be overcome and the effects of co-channel interference can be reduced. In this paper, the performances of equalization techniques by considering 2 transmit 2 receive antenna case (resulting in a 2×2 MIMO channel). Assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK.

Spatially multiplexed MIMO (SM-MIMO) systems can transmit data at a higher speed than MIMO systems using antenna diversity techniques. However, spatial demultiplexing or signal detection at the receiver side is a challenging task for SM MIMO systems. This also addresses signal detection techniques for SM MIMO systems. Consider the N_R*N_T MIMO system in Fig 1. Let H denote a channel matrix with it (j, i)th entry h_{ji} for the channel gain between the ith transmit antenna and the jth receive antenna, j=1, 2,..N_R and i=1,2,.. N_T. The spatially-multiplexed user data and the corresponding received signals are represented by

$$x = [x_1; x_2; \ldots; x_{NT}]^T$$

and

$$y = [y_1; y_2; \ldots; y_{NR}]^T , \qquad (1)$$

respectively, where x_i and y_j denote the transmit signal from the ith transmit antenna and the received signal at the jth receive antenna, respectively. Let zj denote the white Gaussian noise at the jth receive antenna, and hi denote the ith column vector of the channel matrix H. Now, the N_R*N_T MIMO system is represented as

$$y=Hx+z$$

$$=h1x1 + h2x2+ \text{-------} +h_{NT}\, x_{NT} +z$$

Where, $z =[z1; z2; \_\,\_\,\_ ; z_{NR}]^T . \qquad (2)$

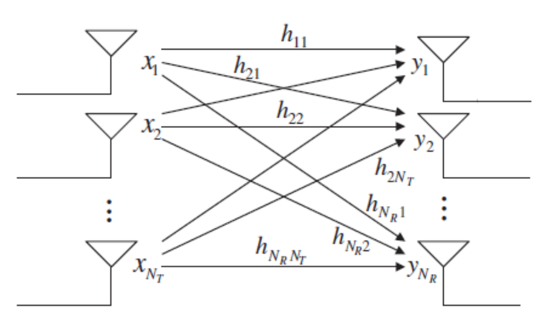

Figure1:Spatially multiplexed MIMO systems.

In the transmission of digital data over the MIMO communication systems, the signal propagates from the transmitter to the receiver through different paths, each associated with a time delay. As such each transmitted symbol is received several times, and each received symbol is disturbed by other symbols in the transmitted sequence, causing inter-symbol interference (ISI). While ideally any multiple access schemes should provide each transmitter/receiver pair with an independent channel, in practice this is often not the case. Due to inherent properties of the multiple access schemes in use, different users interfere with each other, causing the so-called inter-channel interference (ICI), also known as multiple access interference (MAI). The ISI and ICI, due to the multi-path propagation and multi-user impairment, if left uncompensated, will in turn, give rise to high error rate in symbol detection. A solution to this problem is to adopt a technique which can compensate or reduce the ISI and/or ICI in the received signal prior to detection. Such a technique is called channel equalization.

The ultimate goal is to minimize or nullify interference signals from other transmit antennas in the course of detecting the desired signal from the target transmit antenna.To achieve such an objective we need strong equalization techniques to compensate ISI.

- Zero Forcing (ZF) equalization
- Minimum Mean Square Error (MMSE) equalization
- Zero Forcing equalization with Successive Interference Cancellation (ZF-SIC)
- MIMO with MMSE SIC and optimal ordering.

III. MIMO OFDM SYSTEM

Developing high data rate technology with robust and seamless services is the main motivating factor behind both fundamental and applied research in wireless communications today. A key technique in fulfilling this target is the application of multiple transmit and multiple receive antennas,

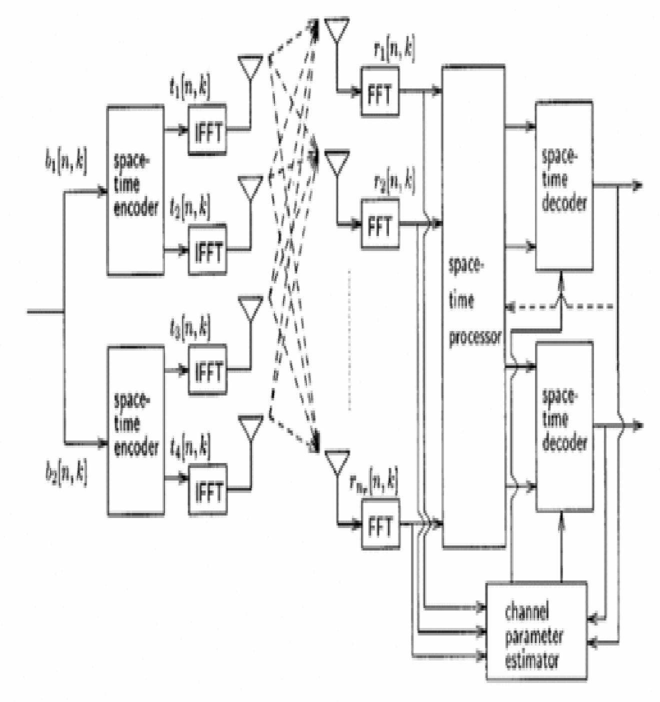

Figure2: Block Diagram of MIMO OFDM system

Which provide an additional spatial degree of freedom. This spatial degree of freedom gives unique opportunities, e.g., for enhancing link reliability, for interference suppression, and for supporting high data rates. However, as the symbol data rate increases in broadband wireless applications, the underlying multiple-input multiple-output (MIMO) channel exhibit strong frequency selectivity. As is well known, orthogonal frequency division multiplexing (OFDM) is a multicarrier transmission scheme that comes with low-complexity (de)modulation, equalization, and decoding to mitigate frequency-selective fading effects. Therefore, a combination of MIMO and OFDM (MIMO-OFDM) techniques appears particularly promising for next generation broadband wireless systems. The block diagram of a MIMO-OFDM system is illustrated in Fig. 2.

Various signal design methods for MIMO and MIMO-OFDM systems have been proposed. A common assumption in the signal design study of MIMO/MIMO-OFDM systems is that the channel coefficients between the pairs of transmit-receive antennas are independent and identically distributed (i.i.d.) complex Gaussian process, which are perfectly known by the receiver. This is an idealistic situation. In practice, however, the channel coefficients are spatially correlated, where the degree of correlation depends mainly on the antenna geometry, the richness of scattering, and the presence of dominant specular components. Moreover, the channel coefficients are in practice not perfectly known, and in some cases they are even unknown. Therefore, it is important to analyze and design signals for MIMO/MIMO-OFDM systems in the presence of correlated channel coefficients on the condition of imperfect channel state information (CSI) or even without any CSI.

Fig. 2 depicts a high level block diagram of the MIMO OFDM system. We consider MIMO–OFDM systems with two transmit antennas and two receive antennas. The total number of subcarriers is N. Basically, the MIMO-OFDM transmitter has $N_t$parallel transmission paths which are very similar to the single antenna OFDM system, each branch performing serial-to-parallel conversion, pilot insertion, *N*-point IFFT and cyclic extension before the final TX signals are up-converted to RF and transmitted.The channel encoder and thedigital modulation can be done per branch, where the modulated signals are then space-time coded using the Alamouti algorithm [6] beforetransmitting from multiple antennas [7] not necessarilyimplemented jointly over all the N_t branches. Subsequently at thereceiver, the CP is removed and *N*-point FFT is performed perreceiver branch. Next, the transmitted symbol per TX antenna iscombined and outputted for the subsequent operations likedigital demodulation and decoding. Finally all the input binarydata are recovered with certain BER.

As a MIMO signalling technique, N_t different signals are transmitted simultaneously over N_t X $N_r$transmission paths and each of those Nr received signals is a combination of all the Nt transmitted signals and the distorting noise. It brings in the diversity gain for enhanced system capacity as we desire. Meanwhile compared to the SISO system, it complicates the system design regarding to channel estimation and symbol detection due to the hugely increased number of channel coefficients. The data stream from each antenna undergoes OFDM Modulation. The Alamouti Space Time Block Coding (STBC) scheme has full transmit diversity gain and low complexity decoder, with the encoding matrix represented as referred in [8] as

$$X = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix}$$

$$X_1 = (X[0] \;\; -X^*[1] \;\; X[2] \;\; -X^*[3] \;.......\; -X^*[N-1])$$

$$X_2 = (X[1] \;\; X^*[0] \;\; X[3] \;\; X^*[2] \;........\; X^*[N-2]) \qquad (3)$$

The vectors X1 and X2 are modulated using the inverse fast Fourier transform (IFFT) and after adding a cyclic prefix as a guard time interval, two modulated blocks X^{g1} and $X^{g2}$are generated and are then transmitted by the first and second transmit antennas respectively. Assuming that the guard time interval is more than the expected largest delay spread of a multipath channel. The received signal will be the convolution of the channel and the transmitted signal. Assuming that the channel is static during an OFDM block, at the receiver side after removing the cyclic prefix, the FFT output as the demodulated received signal can be expressed as in the above equation $[W_1, W_2......W_{NT}]$ denotes AWGN and $H_{m,n}$ is the (single-input single-output) channel gain between the m_{th} receive and n_{th} transmit antenna pair. The n_{th} column of **H** is often referred to as the spatial signature of the n_{th} transmit antenna across the receive antenna array.Knowing the channel information at the receiver, Maximum Likelihood (ML) detection can be used for decoding of received signals for two antenna transmission system, which can be written as

IV. CHANNEL ESTIMATION

Based on those assumptions such as perfect synchronization and block fading, we end up with a compact and simple signal model for both the single antenna OFDM and MIMO-OFDM systems. In training based channel estimation algorithms, training symbols or pilot tones that are known to the receiver, are multiplexed along with the data stream for channel estimation. The idea behind these methods is to exploit knowledge of transmitted pilot symbols at the receiver to estimate the channel. For a block fading channel, where the channel is constant over a few OFDM symbols, the pilots are transmitted on all subcarriers in periodic intervals of OFDM blocks. This type of pilot arrangement, depicted in Fig. 3(a), is called the block type arrangement. For a fast fading channel, where the channel changes between adjacent OFDM symbols, the pilots are transmitted at all times but with an even spacing on the subcarriers, representing a comb type pilot placement, Fig. 3(b) The channel estimates from the pilot subcarriers are interpolated to estimate the channel at the data subcarriers.

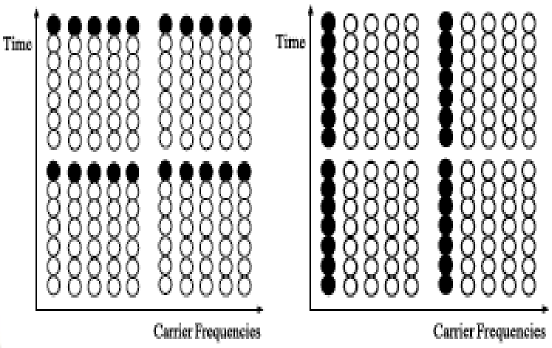

Figure3: Block Pilot And Combo Pilot

V. SISO OFDM CHANNEL ESTIMATION

In block-type pilot based channel estimation, OFDM channel estimation symbols are transmitted periodically, in which all subcarriers are used as pilots. If the channel is constant during the block, there will be no channel estimation error since the pilots are sent at all carriers. The estimation can be performed by using either LS or MMSE [9], [10]. In comb-type pilot based channel estimation, the Np pilot signals are uniformly inserted into X(k) according to the following equation:-

$$X(k) = X(mL + l) \qquad l = 1,2....L-1 \qquad (4)$$

where$L$ = No. of subcarriers / Np and m is pilot carrierindex. If inter symbol interference is eliminated by the guardinterval, we write (4) in matrix notation

$$Y = XFh + W$$

Where,

$$X = diag\{X(0), X(1).....X(N-1)\}$$

$$Y = [Y(0), Y(1).....Y(N-1)]^T$$

$$W = [W(0), W(1).....W(N-1)]^T$$

$$H = [H(0), H(1).....H(N-1)]^T = DFT\{h\}$$

$$F = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix} \qquad (5)$$

Is the DFT matric with

$$W_N^{nk} = \frac{1}{\sqrt{N}} e^{-j2\pi(n/N)k} \qquad (6)$$

If the time domain channel vector h is Gaussian and uncorrelated with the channel noise *W*, the frequency domainMMSE estimate of is given by [3]:

$$\hat{H}_{MMSE} = FR_{hY}R_{YY}^{-1}Y \quad (7)$$

where,

$$R_{hY} = E\{hY\} = R_{hh}F^H X^H$$

$$R_{YY} = E\{YY\} = XFR_{hh}F^H X^H + \sigma^2 I_N \quad (8)$$

are the cross covariance matrix between *h* and *Y* and auto covariance matrix of *Y* respectively. *R*hh is the autocovariance matrix of h, σ^2 represents the noise variance E{$|W(k)|^2$} and I_N is the N X N Identity matrix. To use LS (least square) method for channel estimation, we usually put those observation equations into a matrix form. LS is a well-known method and widely used for estimation. We choose LS rather than other methods like MMSE channel estimation for the simplicity of implementation. The LS channel estimate is represented by:

$$\hat{H}_{LS} = X^{-1}Y \quad (9)$$

the LS estimator is equivalent to what is also referred to as the zero-forcing estimator. In comb-type pilot based channel estimation, an efficient interpolation technique is necessary in order to estimate channel at data sub-carriers by using the channel information at pilot sub-carriers. In the linear interpolation method the channel estimation at the data-carrier *k*, *mL*<*k* < (*m* + 1) *L*, using linear interpolation is given by:

$$H_e(k) = H_e(mL + l) \qquad 0 \le l < L$$

$$= (H_p(m+1) - H_p(m))\frac{l}{L} + H_p(m) \quad (10)$$

whereHp is channel estimation value at pilot frequency. The low-pass interpolation is performed by inserting zeros into the original sequence and then applying a lowpass FIR filter that allows the original data to pass through unchanged and interpolates between such that the mean-square error between the interpolated points and their ideal values is minimized. The spline cubic interpolation produces a smooth and continuous polynomial fitted to given data points.

V. MIMO OFDM Channel Estimation

Similar to the SISO scenario, the LS channel estimation for MIMO-OFDM System between n^th^ transmitter and m^th^ receiver antenna is

$$\hat{H}_{LS}^{(n,m)} = (X^{(n)})^{-1}Y^{(m)} \quad (11)$$

and MMSE channel estimation for MIMO-OFDM System between n^th^ transmitter and m^th^ receiver antenna is

$$\hat{H}_{MMSE}^{(n,m)} = FR_{hY}R_{YY}^{-1}Y^{(m)} \quad (12)$$

where

$$R_{hY} = R_{hh}^{(m,n)}F^H(X^{(n)})^H$$

$$R_{YY} = X^{(n)}FR_{hh}^{(n,m)}F^H(X^{(n)})^H + \sigma^2 I_N \quad (13)$$

Where n = 1, 2….N_T, m = 1, 2….N_R and N_T, N_R are the numbers of transmit and receive antennas, respectively, $X^{(n)}$ is an N X Ndiagonal matrix whose diagonal elements correspond to the pilots of the n^th^transmit antenna and $Y^{(m)}$ is N length received vector at receiver antenna m

VI. CONCLUSION AND FUTURE RESULTS

In my work, I have compared channel estimation based on both block-type pilot and comb-type arrangements in both SISO and MIMO OFDM based systems

The work to be done in later stages is to perform the Channel estimation based on comb-type pilot arrangement is achieved by giving the channel estimation methods at the pilot frequencies and the interpolation of the channel at data frequencies. This study can also be used to efficiently estimate the channel in both OFDM systems given certain knowledge about the channel statistics in future. Also,the MMSE estimator assumes a priori knowledge of noise variance and channel covariance and discussed Space Time Block coding and maximum likelihood decoding in the MIMO OFDM system to enhance its performance further. Wecan also observe the advantage of diversity in MIMO systemresults less BER than SISO system. It can also compares the performance of MMSE with LS, and is observed that the former is more resistant to the noise in terms of the channel estimation

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