Efficient Pilot Based Pre FFT Channel Estimation by using Different Modulation Schemes in OFDM Systems

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Abstract: Channel impairments degrade the performance of accurate data signal detection and decoding. The said problem becomes further severe in low SNR environment. As a result it reduces the performance of channel estimation. To alleviate this problem we develop a pilot based Pre FFT (time domain) channel estimation technique in the presence of Rayleigh fading channel. A novel time domain channel estimation technique is proposed that accurately measure the channel impulse response by using cross correlation between received signal and pilot carriers, especially at low SNR. In addition, the proposed technique enhances robustness in Orthogonal Frequency Division Multiplexing (OFDM) channel estimation by reducing Mean Square Error (MSE). Simulation results show that proposed method provides better accuracy in term of MSE over conventional techniques (LS and MMSE) that estimate the channel impulse response in frequency domain.

Keywords: OFDM, Pre FFT, LS, MMSE, MSE, SNR.

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is becoming a very popular multicarrier modulation technique for transmission of signals over wireless channels. OFDM divides the high rate stream into parallel lower rate data and hence prolongs the symbol duration, thus helping to eliminate Inter Symbol Interference ISI. It also allows the bandwidth of subcarriers to overlap without Inter Carrier Interference (ICI) as long as the modulated carriers are orthogonal. OFDM therefore is considered as an efficient modulation technique for broadband access in a very dispersive environment. Channel estimation has a long and rich history in single carrier communication systems. In these systems, the CIR is typically modeled as an unknown time-varying FIR filter, whose coefficients need to be estimated. Many of the channel estimation approaches of single carrier systems can be applied to multi-carrier systems. However, the unique properties of multi-carrier transmission bring about additional perspectives that allow the development of new approaches for channel estimation of multi-carrier systems. Channel estimation techniques for OFDM based systems can be grouped into two main categories: blind and non-blind.

The blind channel estimation methods exploit the statistical behavior of the received signals and require a large amount of data. Hence, they suffer severe performance degradation in fast fading channels. On the other hand, in the non-blind channel estimation methods, information of previous channel estimates or some portion of the transmitted signal are available to the receiver to be used for the channel estimation. In this article, only the non-blind channel estimation techniques will be investigated. The non-blind channel estimation can be studied under two main groups: data aided and DDCE. In data aided channel estimation, a complete OFDM symbol or a portion of a symbol, which is known by the receiver, is transmitted so that the receiver can easily estimate the radio channel by demodulating the received samples. Often, frequency domain pilots are employed similar to those in new generation WLAN standards (802.11a and HYPERLAN2). The estimation accuracy can be improved by increasing the pilot density. However, this introduces overhead and reduces the spectral efficiency. In the limiting case, when pilot tones are assigned to all sub-carriers of a particular OFDM symbol, an OFDM training symbol can be obtained (block type pilot arrangement).

This type of pilot arrangement is usually considered for slow channel variation and for burst type data transmission schemes, where the channel is assumed to be constant over the burst. The training symbols are then inserted at the beginning of the bursts to estimate the CFR (e.g. WLAN and WiMAX systems). When channel varies between consecutive OFDM symbols, either the training symbols should be inserted regularly within OFDM data symbols with respect to the time variation of the channel (Doppler spread), or the channel should be tracked in a decision directed mode to enhance the receiver performance. Therefore, a novel pilot based channel estimator presented here differs from previous methods in a way that it is based on estimation of channel impulse response in time domain, by using cross correlation between received signal and pilot carriers. In addition, proposed method can accurately measure the channel impulse response at low SNR. In this paper MSE of proposed algorithm is improved significantly as compared to...
conventional LS and MMSE estimators in frequency domain. This paper has been organized in the following way. In Section II, overview of proposed Pre FFT channel estimation technique is explained. Section III addressed methodology used by conventional and proposed Pre FFT channel estimators. The simulation Results are discussed in Section IV. Conclusion of the work is presented in Section V.

II. PROPOSED TECHNIQUE

Pre FFT OFDM system model is shown in Fig. 1. It begins with “signal mapping” block where binary information is mapped according to modulation. Then serial to parallel conversion takes place. After that, pilot sub-carriers \( P(\text{k}) \) are inserted along with data sub-carriers \( D(\text{k}) \), arrangement of pilots and data sub-carriers are shown in Fig. 2. Therefore \( S(\text{k}) \) can be written as

\[
S(\text{k}) = D(\text{k}) + P(\text{k})
\]  

(1)

Fig.1. Typical OFDM Baseband Transceiver.

Then IFFT is applied on \( S(\text{k}) \) samples that transform frequency domain samples \( S(\text{k}) \) into time domain \( s(n) \), which can be shown as

\[
s(n) = \text{IFFT}(S(k)) = \sum_{k=0}^{N-1} S(k) e^{-j2\pi kn/N}
\]  

(2)

Therefore, \( s(n) \) can be written as

\[
s(n) = d(n) + p(n)
\]  

(3)

Finally, after passing through multi-path fading channel, received signal \( r(n) \) becomes

\[
r(n) = h(n) \otimes s(n) + w(n)
\]  

(4)

where \( h(n) \) is channel impulse response and \( w(n) \) is additive white Gaussian noise. Also \( h(n) \) can be expressed as

\[
h(n) = [h_0, h_1, h_2, ..., h_T]
\]  

(5)

Where \( h_0, h_1, ..., h_T \) are the coefficient of channel impulse response and \( T \) is total no of channel taps. \( r(n) \) can be written as

\[
r(n) = h(n) \otimes [d(n) + p(n)] + w(n)
\]  

(6)

To evaluate channel impulse response \( h(n) \), the cross correlation of equation (6) is determined, with locally generated pilot signal. Therefore \( R_{\text{pp}} \) can be written as

\[
R_{\text{pp}}(l) = E[r(n) \otimes h_\text{r}(n) + h_\text{p}(n-l)]
\]  

(7)

Where \( R_{\text{pp}} \) is the cross correlation between received signal and pilot carriers. Similarly \( R_{\text{dp}} \) and \( R_{\text{wp}} \) are cross correlations of data and noise with pilots respectively. Pilots carriers are inserted into data in such a manner that it gives zero when \( l = 0 \). Therefore \( R_{\text{dp}}(n) \) is given as

\[
R_{\text{dp}}(0) = 0
\]  

(8)

It is assumed that \( R_{\text{wp}} \) expected to be relatively small. Therefore \( R_{\text{wp}}(l) \) can be written as

\[
R_{\text{wp}}(l) \equiv 0
\]  

(9)

The convolution of \( h(n) \) and \( R_{\text{pp}}(n) \),

\[
h(n) = [h_0 \delta(n) + h_1 \delta(n-1) + ... + h_T \delta(n-T)]
\]  

(10)

The channel coefficients \( h_0, h_1, ..., h_T \) are available at different location on both sides of zero lag(\(+L\)), but only zero lag position is used at \( (n = 0) \) due to its high energy. Therefore equations can be written as

\[
R_{\text{pp}}(0)(n) = [a_0 \delta(n) + a_1 \delta(n-1) + ... + a_T \delta(n-T)]
\]  

(11)

where \( a_0, a_1, ..., a_T \) are coefficient of \( R_{\text{pp}}(n) \). Therefore \( R_{\text{pp}}(n) \) can be written as

\[
R_{\text{pp}}(n) = [a_0 \delta(n) + a_1 \delta(n-1) + ... + a_T \delta(n-T)]
\]  

(12)

where \( a_0, a_1, ..., a_T \) are coefficient of \( R_{\text{pp}}(n) \). Therefore \( R_{\text{pp}}(n) \) can be written as

\[
R_{\text{pp}}(n) = [a_0 \delta(n) + a_1 \delta(n-1) + ... + a_T \delta(n-T)]
\]  

(13)

The channel coefficients \( h_0, h_1, ..., h_T \) are available at different location on both sides of zero lag(\(+L\)), but only zero lag position is used at \( (n = 0) \) due to its high energy. Therefore equations can be written as

\[
R_{\text{pp}}(0) = [a_0 \delta(n) + a_1 \delta(n-1) + ... + a_T \delta(n-T)]
\]  

(14)

And it gives

\[
h'(n) = [h'_0 \delta(n) + h'_1 \delta(n-1) + ... + h'_{T-1} \delta(n-T)]
\]  

(15)

where \( h'(n) \) represents the estimated channel impulse response. Then take \( \text{NFFT} \) point FFT of \( h'(n) \), which gives

\[
H'(k) = \text{FFT}[h'(n)]
\]  

(16)

where \( H'(k) \) is frequency domain channel transfer function. The error signal \( e \) can be written as

\[
e = |H - H'|
\]  

(17)
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Where \( H \) denotes the actual channel in frequency domain and \( H' \) is estimated channel transfer function. MSE can be written as

\[
E \left\{ \left( |H| - |H'\rangle \right)^2 \right\} = E \left\{ (H - H' \cdot H - H')^2 \right\}
\]

The Normalized Mean Square Error (NMSE) can be calculated by using following expression

\[
NMSE \left( \frac{1}{\tau_{\text{max}}} \right) \left\{ \frac{\hat{H}(k) - H(k)}{\hat{H}(k)} \right\}^2
\]

Where \( \tau_{\text{max}} \) is the number of iteration used for simulation and \( H'(k) \) and \( H(k) \) are the estimated and actual channel transfer function respectively.

III. OFDM CHANNEL ESTIMATION TECHNIQUES

A. Data aided channel estimation

In this subsection, we will review commonly used methods in the data aided channel estimation. Initially, we will consider the methods developed for SISO-OFDM. ICI is assumed not to exist and the CIR is assumed to be constant for at least one OFDM symbol. Hence, \( \Psi \) is a diagonal matrix, where each diagonal element represents the channel between the corresponding received and the transmitted subcarriers. In this case, for the \( nth \) OFDM symbol, the channel at each subcarrier can be related to \( \Psi \) as

\[
H[n, k] = \Psi[k, k].
\]

Furthermore, the external interference is folded into the noise with noise statistics being unchanged. With the above assumption, the expression can be expressed as

\[
Y = \text{diag}(X) H + W,
\]

or

\[
Y[n, k] = H[n, k] X[n, k] + W[n, k].
\]

Here \( H \) and \( W \) are the column vectors representing the channel and the noise at each subcarrier for the \( nth \) OFDM symbol, respectively. In data aided channel estimation, known information to the receiver is inserted in OFDM symbols so that the current channel can be estimated. Two techniques are commonly used: sending known information over one or more OFDM symbols with no data being sent, or sending known information together with the data. The previous arrangement is usually called channel estimation with training symbols while the latter is called pilots aided channel estimation.

B. Pilots Allocation for Data Aided Channel Estimation

For the pilot aided channel estimation, the pilot spacing needs to be determined carefully. The spacing of pilot tones in frequency domain depends on the coherence frequency (channel frequency variation) of the radio channel, which is related to the delay spread. According to the Nyquist sampling theorem, the number of subcarrier spacing between the pilots in frequency domain, \( D_p \), must be small enough so that the variations of the channel in frequency can be all captured, that is,

\[
D_p \leq \frac{1}{f_{\text{max}} \Delta f}
\]

where \( \tau_{\text{max}} \) is the maximum excess delay of channel. When the above is not satisfied, then the channel available at the pilot tones does not sample the actual channel accurately. In this case, an irreducible error floor in the estimation technique exists since this causes aliasing of the CIR taps in the time domain. When the channel is varying across OFDM symbols, in order to be able to track the variation of channel in time domain, the pilot tones need to be inserted at some ratio that is a function of coherence time (time variation of channel), which is related to Doppler spread. The maximum spacing of pilot tones across time is given by

\[
D_t \leq \frac{1}{2f_{\text{max}} \Delta f}
\]

where \( f_{\text{max}} \) is the maximum Doppler spread and \( T_t \) is the OFDM symbol duration. For comb type pilot arrangements, the pilot tones are often inserted for every OFDM symbols.

When the spacing between the pilot tones does not satisfy the Nyquist criteria, then the pilots can still be exploited in a combined pilot-plus DDCE. The pilot spacing in frequency domain needs to satisfy the Nyquist criteria. More insight into Equation reveals that the number of required pilots in frequency domain can be taken as the CIR length. At a first glance, this does not pose any restriction on the pilot spacing that a sufficient number of pilots can be inserted in adjacent subcarriers. However, when the MSE of the time domain LS estimation, which is covered in the next subsection, is analyzed, it is observed that the minimum MSE is obtained when the pilots are equispaced with maximum distance [6]. This is due to the reason that when the pilots are inserted in adjacent subcarriers, then the FFT matrix used in the time domain LS estimation approaches an ill conditioned matrix, making the system performance vulnerable to the noise effect. Hence, from the MSE of LS estimation, the pilots in frequency domain need to be equipowered, equispaced, and their number should not be less than the CIR length. Since the use of pilots is a trade-off between extra overhead and the accuracy of the estimation, adaptive allocation of pilots based on the channel length estimation can offer a better trade-off. As will be seen later in the article, with MIMO and ICI additional requirements will be observed on the pilot subcarriers spacing and properties.

4. SIMULATION RESULTS

A. Pilot based pre FFT channel estimation using BPSK results

Fig. 3 reflects the equation (8). Pilots carriers are inserted into data in such a manner that it gives a value of zero when \( n = 0 \). Therefore, Fig. 3 shows a value of 0.00017 at zero lag, which is negligible compared to other time instant values. Fig. 4 shows a cross correlation of noise with pilot carriers \( R_{wp}(n) \). In channel estimation it plays a very pivotal role because channel MSE is proportional to \( R_{wp}(n) \). Therefore, it is assumed that \( R_{wp}(n) \) is expected to be relatively small, which also reflects from Fig. 4 at zero lag position. An important feature of the proposed Pre FFT SNR estimation is investigated in Fig. 4 [i.e. \( R_{wp}(n) \)]. It has been shown that \( R_{wp}(n) \) is the convolution of channel impulse response...
response \( h(n) \) and pilots autocorrelation \( R_{pp}(n) \). Equation (13) also reflects this property of \( R_{rp}(n) \). It is found that the channel co-efficient \( h_0, h_1, \ldots, h_T \) are present at every \( L \) number of lags. For illustration purpose only the first \( L \) instants coefficient values \((L=Nfft/4)\) are shown in Fig.5. Channel coefficient is estimated at first \( L \) instants because at this location high energy and low MSE values are present. In Fig.6, legend “MMSE CE” represents the minimum mean square error, while “LS CE” denotes the least squares channel estimation and proposed method is shown by “Proposed CE”. The range of SNR used for simulation is -4dB to 20dB. It is evident that throughout the range of SNR values MSE floor of proposed method is smaller as compared to LS and MMSE; it is improved up to 6.4 dB and 3.6 dB at -4dB SNR respectively.

Fig.3. \((R_{dp})\) Cross Correlation between Data and Pilot sub-carriers at 10dB SNR.

Fig.4. \((R_{wp})\) Cross Correlation between Noise and Pilot sub-carriers at 10dB SNR.

Fig.5. \((R_{rp})\) Cross Correlation between Received signal and Pilot sub-carriers.

Fig.6. Mean square error comparison between Least square, MMSE & proposed method.

Fig.7. Mean square error comparison between Least square, MMSE & proposed method.
B. Pilot based pre FFT channel estimation using QAM results:

Fig. 8. Cross Correlation between Data and Pilot sub-carriers.

Fig. 9. Cross Correlation between Noise and Pilot sub-carriers.

Fig. 10. Cross Correlation between Received signal and Pilot sub-carriers.

Fig. 11. Comparing MSE performance of Proposed, LS and MMSE estimator in the presence of Rayleigh Fading channel.

Fig. 12. Comparing NMSE performance of Proposed LS and MMSE estimator in the presence of Rayleigh Fading channel.

Compared to QPSK scheme our proposed QAM scheme for pre FFT channel estimation in Rayleigh Fading channel shows the better MSE performance which is shown in fig.8 to fig.12.

V. CONCLUSION

In this paper, we have investigated use of cross correlation between received signal and pilot sub-carriers for the estimation of the Pre FFT channel impulse response. The MSE performances of LS, MMSE and proposed methods are evaluated in Rayleigh fading channel. Proposed method provides better accuracy in term of MSE over conventional techniques (LS and MMSE) that estimate the channel impulse response in frequency domain.

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