An Adaptive LMMSE Interpolation Algorithm for Channel Estimation in LTE-Advanced Systems

HUIMIN LI, ZHIZHONG ZHANG and FANG CHENG

ABSTRACT

The traditional LMMSE interpolation algorithm assumes that the terminal knows the channel power delay profile (PDP), which is not consistent with the actual situation. This paper proposes an improved LMMSE interpolation algorithm based on RMS estimation. The time-delay parameters of channel first are estimated by pilots, then LMMSE interpolation process in frequency domain is completed by LUT (looking up table) for selection of corresponding frequency domain interpolation matrix. This solves the difficulty in acquiring the second-order channel statistics in the traditional LMMSE interpolation algorithm, and avoiding the real-time inversion process of matrices. Simulation results demonstrate that this method can reduce the complexity and show a good performance of BER and MSE, thus it is more suitable for practical application.

KEYWORDS
Minimum mean square error, Channel estimation, Adaptive parameters

INTRODUCTION

In the LTE-A system, the system communication performance depends largely on the accuracy of the channel estimation. In the engineering project, the wireless channel has a very complex propagation path, which will lead to a large change in multi-path delay. If a fixed multipath delay is used, the mismatch of the correlation function can cause some loss to the channel estimation performance. The optimal LMMSE channel estimation performance can be obtained if the real-time multipath delay spread estimate is obtained according to the change of channel condition in communication and the LMMSE channel estimation parameter is adjusted accordingly. Based on this, the paper presents an adaptive LMMSE interpolation algorithm.

TRADITIONAL LMMSE ALGORITHM

The transmitted data is $X$, the channel frequency response is $H$, the received signal is $Y$, and the Gauss white noise is $W$, then the signal model is as follows:

$$Y = XH + W$$  \hspace{1cm} (1)

The expression of the LS channel estimation algorithm is as follows:

Huimin Li, Zhizhong Zhang, Fang Cheng, College of Communication and Information Technology, Chongqing University of posts and telecommunications, Chongqing, 400065, China

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\[ \hat{H}_{LS} = X^{-1}Y \] (2)

LMMSE channel estimation algorithm is as follow:

\[
\begin{align*}
\hat{H}_{LMMSE} &= \hat{W}H_{LS} \\
W &= R_{hh} (R_{hh} + \frac{\beta}{\text{SNR}} I)^{-1}
\end{align*}
\] (3)

In this formula, \( W \) is filtering matrix in frequency domain; \( R_{hh} \) is channel autocorrelation matrix of all pilot position subcarrier in frequency domain; \( R_{hh} \) is correlation matrix of data subcarrier and pilot subcarrier position in frequency domain; constellation factor \( \beta \) depends on the modulation mode: for QPSK, \( \beta = 1 \); for 16QAM, \( \beta = 17/9 \); for 64QAM, \( \beta = 2.6854 \).

The autocorrelation matrix of the channel is related to the statistical properties of the channel, it expressed:

\[
R_{hh} = E\{HH^H\} = \begin{bmatrix} r_{m,n} \end{bmatrix}
\] (4)

\[
r_{m,n} = \frac{1 - e^{-L|\tau_{rms}|} + 2\pi j(m-n)/N}{\tau_{rms} (1 - e^{-L|\tau_{rms}|}) (1/\tau_{rms} + 2\pi j(m-n)/N)}
\] (5)

We can see from (3), \( \hat{H}_{LMMSE} \) is related to \( R_{hh} \) and SNR, and \( R_{hh} \) is determined by \( \tau_{rms} \). The traditional approach is usually take \( \tau_{rms} \) a constant, but this may lead to the selected parameter values do not match the current channel, and affect algorithm performance.

ADAPTIVE LMMSE INTERPOLATION ALGORITHM

It can be seen that \( \tau_{rms} \) and SNR determine the MMSE filter matrix from the above LMMSE channel estimation algorithm. Based on this, the adaptive LMMSE channel interpolation algorithm is proposed in this paper is as follows:

1) The Root Mean Square (RMS) delay spread is calculated by RMS estimation module;
2) Get the most matching MMSE coefficients according to the LMMSE library;
3) The channel estimation of the data location is obtained by performing LMMSE interpolation on the LS channel estimate.

The overall block diagram is as follows:
Real-Time RMS Estimation Algorithm

The LMMSE interpolation algorithm based on PDP estimation is mainly to estimate the channel power delay distribution (PDP). The PDP estimation idea is that the channel estimation value of the pilot position is obtained by the least squares method, and the time domain channel response value is obtained by IDFT transform. Then the estimated PDP can obtained by the effective path extraction of the response value of the time domain channel. And then use the estimated PDP to calculate the channel delay parameters. Finally, the channel delay parameters are substituted into the traditional LMMSE interpolation algorithm. The specific steps are:

1. Take out the LS channel estimation value of pilots LS to do the corresponding points for the IDFT point operation.

   \[ \hat{h}_{LS} = IDFT(\hat{H}_{LS}) = [\hat{h}(1), \hat{h}(2), \ldots, \hat{h}(N_p)] \]  \hspace{1cm} (6)

2. Calculate the energy \( P \) according to the channel impulse response in the time domain.

   \[ P = [P(1), P(2), \ldots, P(N_p)] = \text{abs}(\hat{h}_{LS})^2 \]  \hspace{1cm} (7)

3. Find the maximum value of the energy \( P_{\text{max}} \), and set the useful signal threshold according to the maximum value \( T_p = P_{\text{max}} / \text{para1} \). Among them, 64 is the empirical value obtained after several simulations, which can be adjusted according to the actual situation.

4. Find the noise energy and the noise power threshold, that is, select the value of \( P \) less than the threshold value \( T_p \) to get \( P1 \), and the average value of \( P1 \) can be considered as the energy of the noise. According to the noise energy to set the noise threshold \( T_N \), in which the value of \( \text{para2} \) is 6 according to the simulation experience, and the parameters can be adjusted according to the actual situation.

   \[ T_N = P_{\text{max}} / \text{para1} \]  \hspace{1cm} (8)
(5) Sort the value of \( P \). If the number of multi-path is 6, select the first six maximum values of \( P \) to get \( P2 \), and record its location information.

\[ [P, Pos] = \text{sort}(P, 'descend') \]  

(9)

\[ P2 = [P(1), P(2), \ldots, P(L)] \]  

(10)

\[ Pos = [Pos(1), Pos(2), \ldots, Pos(L)] \]  

(11)

(6) Choose the values which are greater than or equal to the noise threshold \( T_N \) from \( P2 \) to get \( P3 \) and retain its position. The every value of \( P3 \) are divided by the maximum value to get \( P_k \). And then according to the location information of \( P3 \) to obtain multipath delay.

\[ \tau_k = Pos(k) \times T \times N_{pp} / (12 \times NRB) \]  

(12)

(7) Calculate the Root Mean Square (RMS) of the delay spread.

\[ \tau_{rms} = \sqrt{\bar{\tau}^2 - \bar{\tau}^2} \]  

(13)

\[ \bar{\tau}^2 = \frac{\sum_k P_k \tau_k^2}{\sum_k P_k} \]  

(14)

\[ \bar{\tau} = \frac{\sum_k P_k \tau_k}{\sum_k P_k} \]  

(15)

Storage and Selection of LMMSE Parameters

In order to reduce the complexity, LMMSE parameters can be calculated and stored according to different RMS and SNR. When you need to use the parameters, and then look up the table call (LUT, Look Up Table). In this paper, the LMMSE interpolation is completed by estimating the delay parameter of the channel, selecting the closest channel PDP, and obtaining LMMSE parameters through the LUT.

SIMULATION RESULTS

To verify the performance of this algorithm, the location of channel pilot estimation using LS algorithm, interpolation of data location are the mean copy in the time domain, using different interpolation algorithms in the frequency domain, performance comparison in bit error rate (BER) and mean square error (MSE). The simulation environment as follows: the system bandwidth is 10MHz, use the 16QAM
modulation mode, the transceiver antenna is configured to be $4 \times 4$, and the channel model is EPA. The simulation results are shown in figure 2 and figure 3.

A comparison of system error rates under different interpolation algorithms is shown in Figure 2. Among them, the "Linear" represents the linear interpolation algorithm, "Linear" represents the linear interpolation, "DFT" said interpolation algorithm based on DFT, "LMMSE" represents the ideal LMMSE interpolation algorithm, the "LMMSE_PDP" curve representing the performance of the improved LMMSE interpolation algorithm, and the curve of BER performance as a reference under ideal channel frequency response.

We can see from Figure 2, the improved LMMSE interpolation algorithm performance slightly worse than LMMSE algorithm under ideal conditions (the algorithm requires the channel characteristics in advance) performance, but better than the linear interpolation algorithm and DFT interpolation algorithm. When the SNR is greater than 15dB, the improved LMMSE interpolation algorithm is approximated to the ideal LMMSE algorithm in MSE performance. And we can see from Figure 3, the BER performance of the ideal LMMSE algorithm is closest to the PERFECT performance of BER, and the performance of LMMSE_PDP interpolation algorithm is less than that of the traditional LMMSE algorithm. Since the improved algorithm can estimate the channel delay parameters in real time, the bit error rate is still very low under the condition of small SNR, and it is very close to the LMMSE interpolation algorithm in the ideal state.

![Figure 2. MSE performance curve.](image)

"Linear", DFT, LMMSE, LMMSE_PDP.
SUMMARY

The implementation of LMMSE interpolation algorithm requires channel prior information, but it is often difficult to obtain in the actual environment. In view of this problem, this paper estimates the channel delay parameters effectively in the view of channel energy, and then gets more accurate autocorrelation matrix. Simulation results show that the proposed algorithm has better performance of MSE and BER. Compared with LMMSE algorithm, the proposed algorithm avoids to calculation of channel statistics directly. The complexity of the algorithm is reduced, and the efficiency of the system is improved. The algorithm is simple and feasible, so it is suitable for engineering application.

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REFERENCES