Channel Estimation Algorithm Based on Demodulation Reference Signal in 5G

Bingguang Deng, Xiaofang Min^(✉), Siyi Yu, and Qianqian Ye

School of Communication and Information Engineering, Chongqing University
of Posts and Telecommunications, Chongqing, China
S180101183@stu.cqupt.edu.cn

Abstract. In order to track 5G downlink shared channel in real time and meanwhile to reduce computational complexity, a linear minimum mean square error algorithm based on demodulation reference signal adaptive parameter estimation is proposed. Firstly, the SNR nonlinear centralized optimization problem is transformed into a multivariable linear programming problem due to the restriction of non-uniform energy distribution in time-domain channel. Secondly, considering the uncertainty of multipath delay channel, the combination of negative exponential distribution model and generalized correlation algorithm is taken advantage of so that the original problem is turned into a specific parameter optimization problem. At the same time, according to the obtained delay parameters and SNR, the most appropriate interpolation coefficient is selected for the LMMSE channel estimation by combining with the sliding window, which avoids the matrix inversion process, realizes the real-time matching of parameters, and reduces the computational complexity. The simulation results show that the proposed algorithm has better system performance compared with the classical channel estimation algorithm.

Keywords: 5G · Linear minimum mean square error · SNR · Time delay · Channel estimation

1 Introduction

With the function of effectively improving spectrum utilization and realizing multi-user access, Orthogonal Frequency Division Multiplexing (OFDM) is frequently applied in 5G system. The quality of channel estimation determines whether OFDM technology can be implemented efficiently. In a consequence, it is very important for communication system to obtain effective data information by appropriate methods. The data processing of the channel estimation module of Physical Downlink Shared Channel (PDSCH) has a direct effect on the performance of the whole 5G system, so it is of great importance to find a method easy to implement and with better system performance. In literature [1], an algorithm based on Fast Fourier Transformation (FFT) operation, circular shift operation and fast Toplitz matrix vector multiplication to obtain the autocorrelation matrix has been put forward. In literature [2], it is pro-posed that the method of estimating the noise variance in the time domain through the leading symbol has strong robustness, yet multiple iterations increase the complexity. In

H. Gao et al. (Eds.): ChinaCom 2020, LNICST 352, pp. 371–380, 2021.
https://doi.org/10.1007/978-3-030-67720-6_25

literature [3], a linear minimum mean square error channel estimation algorithm based on compressed sensing has been raise, which improves the frequency band utilization. These techniques may increase the computational complexity, so there are difficulties to apply them in practice. Literature [4] proposes two-dimensional linear minimum mean square error channel estimation method for OFDM systems, which can reduce the computational complexity, but this algorithm is only suitable for slow fading channels. In literature [5], the channel delay parameters are estimated, and then the channel estimation is carried out by using the lookup table, under the condition of high SNR, this algorithm suffers from flat effect, which may degrade system performance. In literature [6], a new low rank minimum mean square error method is pro-posed to simplify the filtering matrix and diagonal matrix, which has good system performance, but involves the acquisition of channel statistics.

Aiming at the difficulty and high complexity of channel prior information acquisition, an adaptive parameter channel estimation method based on Demodulation Reference Signal (DRMS) is proposed in this work. According to the characteristics of energy and power delay profile distribution in 5G time-domain channel, the methods of impulse point decision and difference approximation are adopted to estimate the delay parameters and Signal to Noise Ratio (SNR) in real time respectively, and the channel estimation is carried out in combination with the sliding window. In the light of the simulation results, this method achieves a good compromise between system performance and computational complexity compared with the classical channel estimation algorithm.

2 System Module

Estimation of DRMS in 5G downlink Shared channel is divided into two parts. At the pilot, the algorithm of Least Square (LS) or Linear Minimum Mean Square Error (LMMSE) is adopted; at the data, interpolation algorithm is adopted [7, 8]. Including:

- Channel estimation at pilot adopts LS algorithm;
- LMMSE interpolation is used for data locations in the frequency domain;
- Linear interpolation is adopted at the location of time-domain data. After the above steps, channel responses of all reference signals are finally obtained.

5G system has made a new design for reference signal. The function of the most important Cell Reference Signal (CRS) in LTE system will be carried by DRMS, Channel State Information Reference Signal (CSI-RS), Phase Tracking Reference Signal (PTRS) et al. In particular, DRMS is used for channel estimation of PDSCH in 5G systems, which uses LS algorithm to complete the estimation of the initial channel frequency response.

Based on the existing Minimum Mean Square Error (MMSE) algorithm, the instantaneous power of each frame is replaced by the average power of each subchannel, so LMMSE denotes $\hat{H}_{LMMSE} = R_{HH}\left(R_{HH} + \frac{\beta}{SNR}I\right)^{-1}\hat{H}_{LS}$ as the channel responses, where $W = R_{HH}\left(R_{HH} + \frac{\beta}{SNR}I\right)^{-1}$ represents the interpolation matrix, R_{HH}

represents the correlation matrix, I is an unit matrix, β is a constant, which depends on what kind of modulation is used. When the modulation is QPSK, $\beta = 1$; 16QAM, $\beta = 17/9$; 64QAM, $\beta = 2.6854$; 256QAM, $\beta = 3.4371$.

It can be seen from the expression that the emphasis lies in the calculation of correlation matrix and SNR, as well as the inverse operation of the matrix [9, 10]. The former constitutes the interpolation filter coefficient, which is related to the system performance, while the computational complexity of LMMSE algorithm is mainly reflected in the process of matrix inversion.

This paper mainly studies the frequency domain interpolation algorithm based on LMMSE to apply in practical engineering. Considering its practicability from different perspectives, there is a design scheme.

3 Proposed Algorithm

The expression of LMMSE channel estimation correlation matrix is as follows:

$$R_{HH} = E\left[HH^{H}\right] = \left[r_{x,y}\right] \tag{1}$$

$$r_{x,y} = \frac{1 - \exp\left\{-\tau_m\left[j\frac{2\pi}{N}(x-y) + \frac{1}{\tau_r}\right]\right\}}{\tau_r\left[1 - \exp\left(-\frac{\tau_m}{\tau_r}\right)\right]\left(\frac{1}{\tau_r + j\frac{2\pi}{N}(x-y)}\right)} \tag{2}$$

The maximum diameter delay τ_m and root mean square delay τ_r determine $r_{x,y}$ [11, 12]. The traditional method uses a channel model with uniform delay distribution and negative exponential power delay profile, and assumes that the root mean square delay is a fixed constant.

3.1 Proposed Algorithm Design

The flow chart of 5G downlink Shared channel DRMS channel estimation algorithm are shown in Fig. 1. Specific steps of the algorithm are given as:

- Obtain DRMS reference signals and then use LS algorithm for DRMS estimation.
- Conduct the LMMSE frequency domain interpolation at the data points according to the estimated channel value obtained in the previous step.
- According to the characteristics of energy distribution in the time-domain of the channel, the SNR is calculated by tracking the distribution of the channel in real time, and the delay parameters are obtained by using correlation method.
- Calculate the frequency domain LMMSE Wiener filtering coefficient through the obtained delay parameters and SNR.
- In the frequency domain, the sliding window and LMMSE algorithm are combined to estimate the data signals.
- Using linear interpolation to estimate the data signals in the time domain.

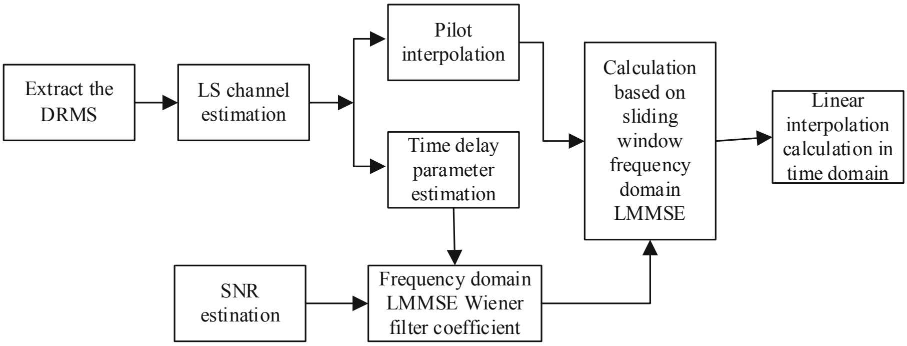

Fig. 1. Adaptive LMMSE channel estimation

3.2 Proposed Adaptive Delay Parameter Estimation

Real-time estimation of delay parameters can realize adaptive adjustment of the number of pilots at the sending end, and the channel estimation performance can be improved effectively. In order to solve the channel mismatch problem caused by delay parameters, this paper randomly assigns the delay value and estimates parameters in the channel model with negative exponential distribution of power delay profile. The delay power is calculated as $P(\tau) = Ce^{-\tau/\tau_r}$, C represents the maximum value of multipath power spectrum. The relation between delay power and multipath delay can convert $r_{x,y}$ into

$$r_{x,y} = \frac{1 - \theta \exp\left(\tau_m 2\pi j \frac{x-y}{N}\right)}{(1-\theta)\left[1 - \frac{-\tau_m}{ln\theta} 2\pi j \frac{x-y}{N}\right]} \tag{3}$$

The correlation matrix problem is transformed into the maximum path delay problem, which improves the accuracy and reliability of parameters.

In order to obtain the instantaneous correlation value at pilot frequency of OFDM symbol, Correlation operation is carried out for frequency domain channel response at pilot. The instantaneous correlation value is presented as

$$\hat{R}_H(\Delta) = E_i\left[\hat{H}(m)\hat{H}^*(m+\Delta)\right] \tag{4}$$

Considering the characteristic of concentrated energy distribution of time-domain channel, the power delay spectrum is obtained by Inverse Discrete Fourier Transform (IDFT). This can formally be expressed as

$$\hat{r}_h(l) = IDFT\left\{\hat{R}_H^n(\Delta)\right\} = \sum_{\Delta=0}^{N-1} \hat{R}_H^n(\Delta) e^{-j2\pi\Delta/N} \tag{5}$$

Where $l = 0, 1, \ldots, N-1$. Since the power delay spectrum is approximately symmetric with $N/2$ as the center, the channel impulse points are determined by the following decision

$$\hat{r}_h(l) > (\hat{r}_h(l-1) + \hat{r}_h(l+1))/2 \tag{6}$$

The position parameters of the peak element of the impulse point are obtained, $l \times T_s$ is the delay time of each path, and T_s is the tap interval.

The maximum path delay spread value of the channel is a relative delay value, which is actually the value of the power attenuation udB of the strongest multipath signal. So define $E = \hat{r}_h(0) \cdot 10^{-u/10}$ to determine the number of taps that is set as $G = \underset{l \in [1,2,\ldots,N/2]}{\arg\max} \{\hat{r}_h(l) > E\}$, where u is the threshold value of power attenuation corresponding to the maximum diameter delay. After the impulse point decision and threshold setting, the maximum diameter delay extension value τ_m is obtained by multiplying the tap interval and the tap number. The process is shown in Fig. 2.

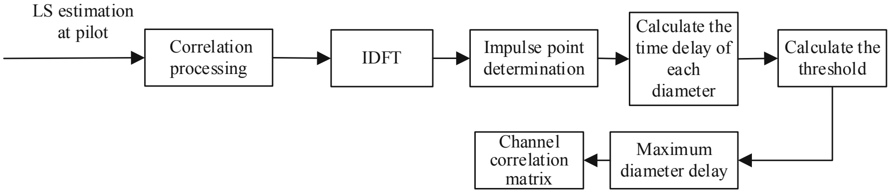

Fig. 2. The process of maximum diameter delay estimation

3.3 Proposed SNR Estimation

The SNR is estimated according to the characteristic that channel energy sparsely distributes on M channel paths, and always tends to be distributed on K paths of what the size we don't know. Therefore, this paper proposes an adaptive SNR estimation method to track the channel energy distribution in real time. This method can determine not only the size of K, but also its corresponding specific location. It is also suitable for the channel with decentralized energy distribution.

Receiver signal in time domain is $r(i) = y(i) + w(i)$, where $r(i) = r_I(i) + jr_Q(i)$ represents the received signal. By splitting the real part and the imaginary part, the received signal power can take the form

$$P = \sum_{i=0}^{i=M-1} P(i) = \sum_{i=0}^{i=M-1} \left[|real(r(i))|^2 + |imag(r(i))|^2 \right] \tag{7}$$

The noise on each path in the channel is different, but its noise power always approaches one value. Assuming that the noise power of each path is σ^2, there are M paths. So $\bar{P} = \frac{P}{M} > \sigma^2$ is the average power, where P represents the total power of received signal. According to the above analysis, in order to determine the exact location of the signal, the algorithm gives the decision condition $P(i) - \bar{P} > 0$, where $P(i)$ represents the received signal power of path i, which must be the value of 0, 1, 2, …, K.

Exclude the determined signal path, calculate the average power of the remaining $M - i$ paths, and repeat the first two steps until it meets $|P(i) - \bar{P}| < \delta$ (δ is a positive number approaching 0). After determination, the remaining path, which does not meet the above conditions, is the path of noise, so as to determine the K paths of signal distribution.

Given that the noise power of each path is basically the same, the average noise power of the last $M - K$ paths is calculated as

$$\sigma^2 = \frac{\sum_{i=K}^{M-1} P(i)}{M - K} \tag{8}$$

Therefore, the SNR is estimated with

$$SNR = \frac{P - N\sigma^2}{N\sigma^2} = \frac{P}{N\sigma^2} - 1 \tag{9}$$

The process of adaptive SNR estimation is shown in the Fig. 3.

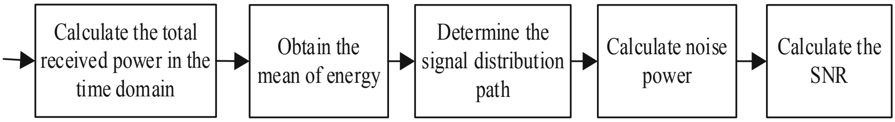

Fig. 3. The process of adaptive SNR estimation

In practical engineering application, to save resources as much as possible, the consideration of computational complexity is the key. Suppose that there are N pilots in OFDM symbol, and the initial subspace dimension of the estimated signal is assumed to be r through adaptive estimation. Each OFDM symbol channel estimation achieves a moving average instead of statistical autocorrelation values. The next time estimation is an orthogonal iteration, the value is the average of the previous estimation. The total computation is $O(N(r)^2)$, but the traditional LMMSE estimation computation is $O(N^3)$. This method reduces the dimensions of the correlation matrix inversion, and the number of calculations for plural matrix multiplication and addition.

4 Simulation Results and Discussion

4.1 Simulation Parameter

In order to verify the validity and stability of the proposed estimation algorithm, MATLAB is used to simulate it. Simulation parameters are shown in Table 1, and the channel multipath number is generated randomly between timely delays.

Table 1. Simulation parameters

Parameter	Value
System bandwidth	20 M Hz
Modulation method	64QAM
Channel model	Negative exponential distribution
Subcarrier number	512
Subcarrier interval	7.815 kHz
Pilot model	Comb
FFT	2048
Sampling frequency	30.76 MHz
Cyclic prefix	Normal CP

Figure 4 shows the simulation of power delay spectrum under different SNR. It can be seen from the figure that the change of SNR has little influence on the delay spectrum, and only when the SNR is very small (0–10 dB) may generate noise impulse points leading to misjudgment. It is shown that the multipath time delay estimation algorithm presented in this paper is not affected by channel noise and has good stability.

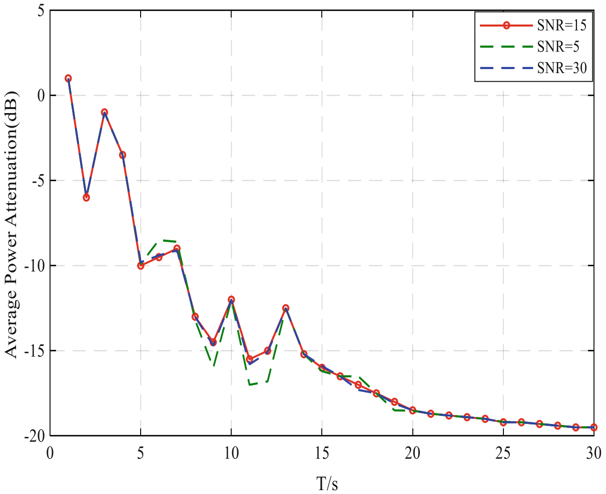

Fig. 4. Power delay spectrum for different SNR

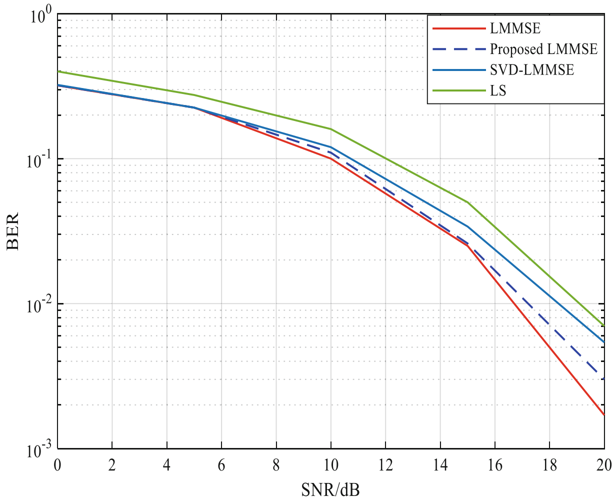

Fig. 5. Comparison of BER for different algorithms

Figure 5 depicts Bit Error Rates (BER) generated by different channel estimation algorithms. Compared to Singular Value Decomposition (SVD) LMMSE interpolation algorithm, the improved LMMSE algorithm has a smaller BER. The BER performance of LMMSE algorithm is the most ideal. Although the performance of the improved LMMSE interpolation algorithm is not completely consistent with the ideal channel, its system performance is relatively better than that of other interpolation algorithms. The simulation results show that when the SNR is relatively small, the improved LMMSE algorithm has lower BER and better performance. However, BER decreases faster when SNR is greater than 15 dB. This is because the algorithm makes full use of the correlation between symbols to track the signal information in real time. And it estimates the dimension of signal subspace within a small error range to reduce the estimation error.

Figure 6 shows the Mean Square Error (MSE) performance of different algorithms. With the increase of SNR, the MSE of the four algorithms decreases. Under the same SNR, the MSE of LS interpolation algorithm is the largest. The improved LMMSE algorithm is superior to SVD-LMMSE algorithm. Moreover, with the increase of SNR, the improved LMMSE algorithm is very close to the characteristic curve of the ideal LMMSE algorithm. The reason is that the improved algorithm takes full account of the characteristics of uneven delay distribution and concentrated energy distribution in the channel to realize the adaptive estimation of parameters, and make the actual estimation as close as possible to the ideal channel.

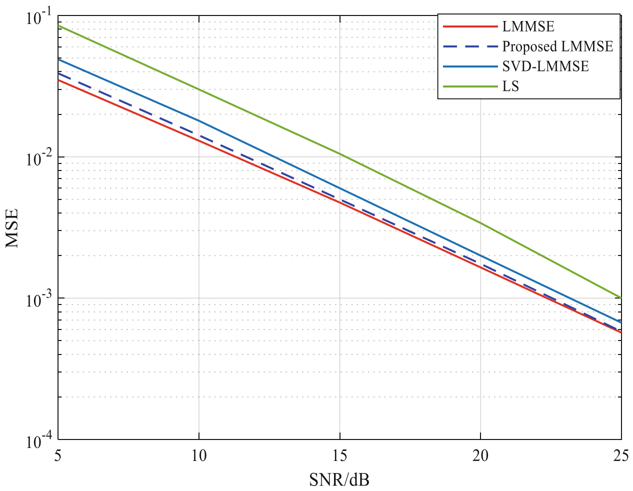

Fig. 6. Comparison of MSE for different algorithms

5 Conclusion

Based on the characteristics of the 5G downlink shared channel, the time delay parameter and SNR estimation of the LMMSE channel estimation algorithm are optimized under the condition of not requiring the channel statistics information, and better system performance is obtained. A corresponding model is established for the proposed time delay estimation optimization method. Moreover, the methods of frequency domain correlation method and impulse point decision are combined to simplify the multivariate solution to a single variable by using the negative exponential distribution channel model. For SNR optimization, considering the characteristics of channel energy distribution, channel distribution decision conditions are set to track the channel information in real time, and fixed variable estimation is converted into adaptive estimation, so as to improve the information accuracy. Ultimately, the slid-ing window LMMSE algorithm is made use of to obtain the channel response of the whole channel. This paper also attempts to compare the proposed method with other different methods of channel estimation. Simulation results demonstrate that com-pared with the traditional LMMSE algorithm, the improved algorithm reduces the computational complexity and effectively reduces the waste of hardware resources.

Acknowledgment. This work is supported by National Key Research and Development Project (No. 2018YFB2100200).

References

1. Khlifi, A., Bouallegue, R.: A very low complexity LMMSE channel estimation technique for OFDM systems. In: Vehicular Technology Conference (VTC Spring), pp. 1–5, May 2015

2. He, P., Li, Z., Wang, X.: A low-complexity SNR estimation algorithm and channel estimation method for OFDM systems. In: International Conference on Information Science and Technology, pp. 698–701, April 2014
3. Ge, L., Zhang, Y., Chen, G., Tong, J.: Compression-based LMMSE channel estimation with adaptive sparsity for massive MIMO in 5G systems. IEEE Syst. J. **13**(4), 3847–3857 (2019)
4. Choi, Y.J., Bae, J.H., Lee, J.W.: Low-complexity 2D LMMSE channel estimation for OFDM systems. In: International on Vehicular Technology (VTC2015-Fall), pp. 1–5, September 2015
5. Duan, H.G., Tian, M., Li, Y.L.: DMRS based channel estimation algorithm in LTE-A system. Commun. Technol. **49**(11), 1424–1428 (2016)
6. Tang, R., Zhou, X., Wang, C.: A novel low rank LMMSE channel estimation method in OFDM systems. In: International Conference on Communication Technology (ICCT), pp. 249–253, October 2017
7. Savaux, V., Bader, F., Louët, Y.: A joint MMSE channel and noise variance estimation for OFDM/OQAM modulation. IEEE Trans. Commun. **63**(11), 4254–4266 (2015)
8. Liu, W., Li, X.: An improved LMMSE channel estimation algorithm of LTE system. In: International Conference on Computational and Information Sciences (ICCIS), pp. 231–234, August 2012
9. Hei, S.S., Wang, X.Q.: Block sliding window channel estimation algorithm based on LMMSE. Comput. Eng. Appl. **53**(16), 79–83 (2017)
10. Kalakech, A., Berbineau, M., Dayoub, I., Simon, E.P.: Time-domain LMMSE channel estimator based on sliding window for OFDM systems in high-mobility situations. IEEE Trans. Veh. Technol. **64**(12), 5728–5740 (2015)
11. Senol, H.: Joint channel estimation and symbol detection for OFDM systems in rapidly time-varying sparse multipath channels. Wireless Pers. Commun. **82**(3), 1161–1178 (2015)
12. Sheng, Z., Tuan, H.D., Nguyen, H.H., Fang, Y.: Pilot optimization for estimation of high-mobility OFDM channel. IEEE Trans. Veh. Technol. **66**(10), 8795–8806 (2017)