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Research on adaptive filter of Orthogonal Frequency Division Multiplexing Signals Based on LMS Algorithm

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Abstract:
This research focuses on processing signals in orthogonal frequency division multiplexing (OFDM) systems, especially adaptive filter techniques for multipath effects and noise interference. By deeply discussing the application of the LMS algorithm in the OFDM system, this paper proposes an adaptive filter scheme founded upon the LMS algorithm, which adaptively changes filter parameters to increase signal transmission efficiency and speed. The principles of the LMS algorithm and that of the adaptive filter, as well as the applicability and performance of the filter in the OFDM system, are analyzed and studied. Simulation experiments are conducted by MATLAB for the purpose of verifying the efficiency of the proposed scheme in reducing signal interference and improving system performance. The results indicate adaptive filter technology founded upon LMS algorithm has a wide application prospect in OFDM system, and plays a strong support for the development of wireless communication technology.

Keywords: OFDM; LMS algorithm; adaptive filter; MATLAB; reducing signal interference

1. Introduction

As science and technology and wireless communication technology are constantly developing, Orthogonal Frequency Division Multiplexing (OFDM) technique is extensively adopted in 4G and 5G communication systems because of its super high data transmission rate together with good anti-multipath fading ability. At the same time, the high flexibility (OFDM allows for adaptive modulation and coding strategies, where different parts of the spectrum can be controlled adaptively) and the simplicity in equalization (OFDM systems require a simpler equalization process compared to single-carrier systems) make it become one of the core technologies of modern communication system (Ramteke et al. 2018; Vishwaraj and Ali, 2019; Almutairi and Krishna. 2022).

However, in the process of the actual communication, OFDM system is susceptible to multi-path effect and noise, which leads to signal interference. This noise has to be meticulously considered in the process of establishing an OFDM-based communication system (Garcia Armada, 2001; Abuabed, 2017). To elimi-

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nate this unbearable noise during communications, many previous works have focused on the improvement of the OFDM system. The previous works on the improvement of the performance of OFDM systems has indicated that adaptive filter technology plays an important role in signal processing. Filtered-orthogonal frequency division multiplexing serves as one of the most protruding communication technologies (Almutairi and Krishna. 2022).

The adaptive filtering founded upon the Least Mean Square (LMS) algorithm is a self-adaptive algorithm employed to iteratively renew weights to minimize squared error. It is extensively applied in signal processing & filter fields. LMS algorithm aims to utilize the steepest descent method for iterative calculation founded upon its error between the expected signal and actual signal, thus making its result closer to the optimal value (Ferrara, 1980; Sireesha et al 2013; Shahzad et al. 2024)

Based on the background, this research focus on simulate LMS adaptive filter in OFDM system and show the application effect of the LMS adaptive filter in different environments.

2. Proposed Algorithms Analysis

2-1 Principle of Adaptive Filter

The adaptive filtering principle is shown in Figure 1.

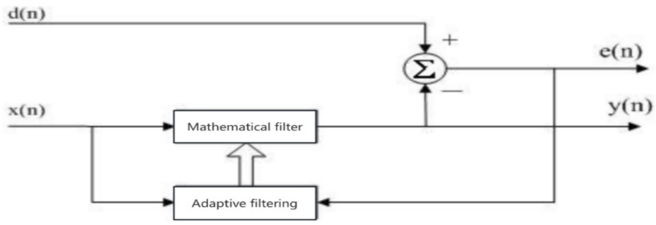

Figure 1. Adaptive filtering schematic

In adaptive filters, the filtering of the system is divided into two stages. The input signal (x (n)) is passed through the mathematical filter to get the output signal (y(n)). Then the output signal is compared with the expected signal (d (n)) to get the error signal (e(n)). The LMS algorithm is used to modulate filter parameters as per its error signal. This process is iterative, which means that the filter will periodically check the error signal and fine-tune its filter parameters as per current error value, so as to optimize the filtering effect.

2-2 LMS Algorithm

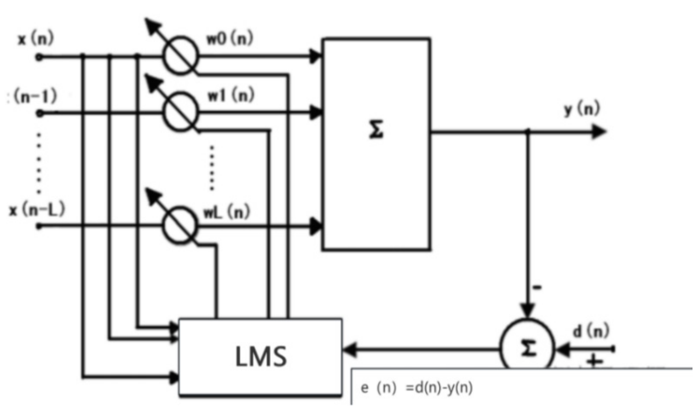

Figure 2. L-order weighted adaptive transversal filter schematic diagram

LMS algorithm, also known as minimum mean square error algorithm, is a common adaptive filter algorithm widely utilized in signal processing, noise cancellation, anti-interference and other fields. In the adaptive filter parameter function mentioned above, this algorithm plays a crucial role. The LMS algorithm formula is derived by taking an L-order weighted adaptive filter as an instance. An l-order weighted adaptive filter is shown in Figure 2.

LMS algorithm formula derivation explains the principle

Input signal X(n):

$$X(n) = [x(n)x(n-1)\ldots\ldots x(n-N+1)]^T \quad (1)$$

Weighting coefficient W(n):

$$W(n) = [w_0(n)w_1(n-1)\ldots\ldots w_{N-1}(n)]^T \quad (2)$$

“T” is transpose, “n” is time series, and “N” is filter order.

Output signal X(n):

$$y(n) = w^T(n)X(n) \quad (3)$$

Therefore, for the LMS filter structure, the error(e(n)) is

$$e(n) = d(n) - y(n) = d(n) - w^T(n)X(n) \quad (4)$$

d(n)is Reference signal

Mean error signal square:

$$\epsilon(n) = E[e^2(n)] \quad (5)$$

Gradient of mean square error performance surface is calculated as per formula (4) and (5) :

$$\nabla(n) = \frac{\partial\epsilon(n)}{\partial w} = 2e(n)\frac{\partial\epsilon(n)}{\partial w} = -2e(n)X(n) \quad (6)$$

Full vector formula of steepest descent approach:

$$W(n+1) = W(n) - \mu\nabla(n) \quad (7)$$

obtained from formula (6) and formula (7):

$$W(n+1) = W(n) + 2\mu e(n)X(n) \quad (8)$$

μiss tep factor, $0 < \mu < 2/\mu_{max}$, μ_{max} is the largest eigenvalue of the autocorrelation matrix R of input signal

3 Simulation Experiment Running and Analysis

3-1 Adaptive Filtering Simulation of OFDM System

In this system simulation, MATLAB programming language is used for simulation design. According to the characteristics of the OFDM signal, the OFDM signal model is established, and an adaptive filter founded upon the LMS algorithm is designed to filter and simulate under different channel conditions (such as noise, interference, multipath channel, etc.). In this simulation experiment, Gaussian noise is used to simulate the real noise, and a sinusoidal signal model is added to interfere with the signal. System simulation parameters, such as signal-to-noise ratio, bit error rate, and convergence curve, have been set to fully evaluate overall filter performance.

3-2 Simulation Idea and Parameter Setting

Before simulating the adaptive filter system of OFDM signal, the filtering effect of Wiener filter and adaptive filter is compared.

Figure 3 shows the OFDM signal simulation process.

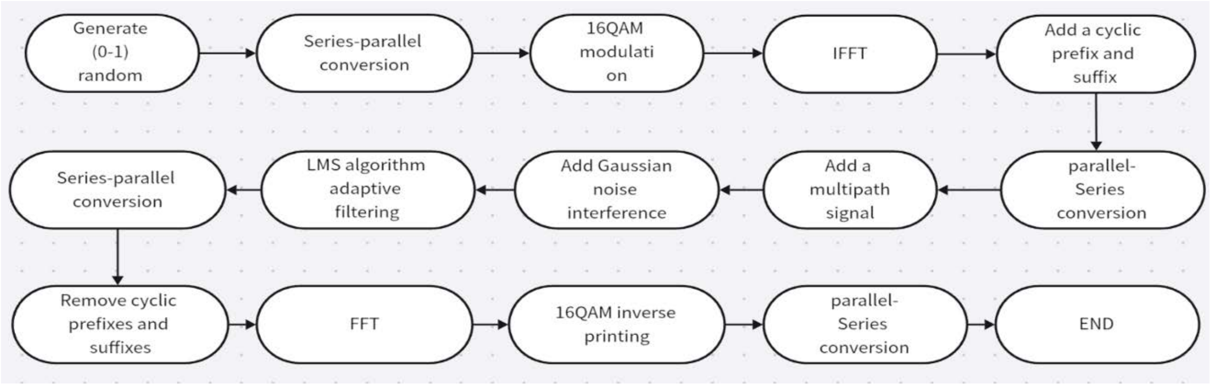

Figure 3. Simulation idea figure of OFDM signal

Simulation parameters of this system are as follows: quantity of subcarriers is 200, total number of symbols is 100, IFFT/FFT length is 512, modulation mode is 16QAM, cyclic prefix length is 128, and signal-to-noise ratio is 20dB.

3-3 Simulation Result

3-3-1 Comparison Experiment Between Adaptive Filter and Wiener Filtering

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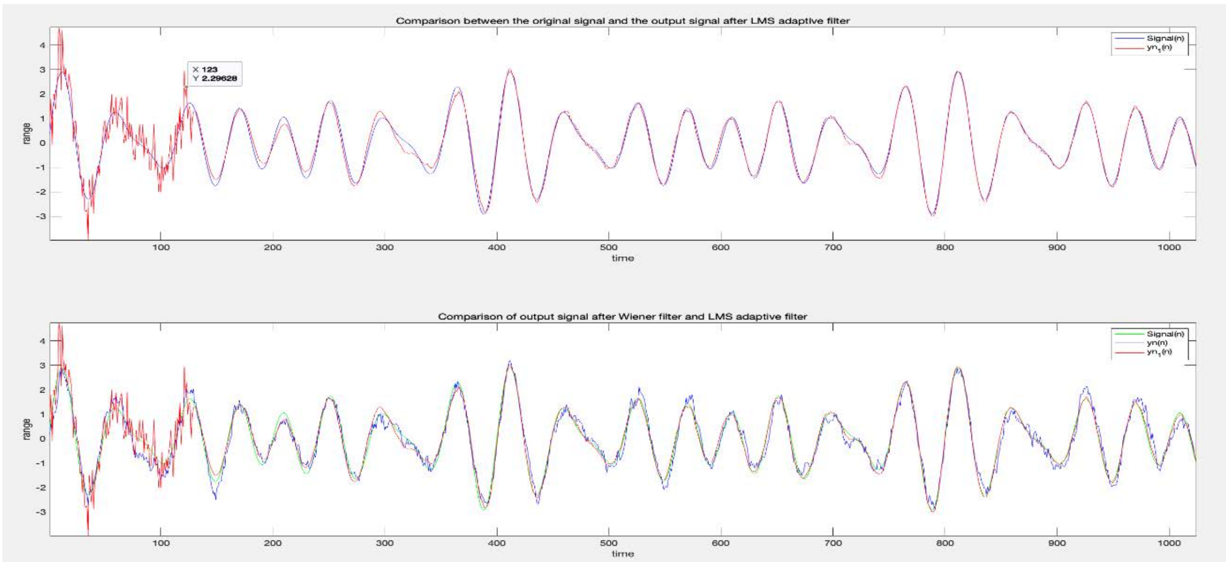

Figure 4. Results of adaptive filter and Wiener filtering

In Figure 4, yn_1(n) is the original Signal, yn(n) is the Wiener filtered signal, and Signal(n) is an adaptive filtered signal. In the upper and lower figures, the above figure is the comparison between the adaptive filter result and the original signal, and the figure as follows is the comparison between the adaptive green filter and Wiener filter and the original signal.

By comparing the waveform results of Wiener filtering and adaptive filtering, it can be seen that adaptive filtering has a better filtering effect for signals with longer signal lengths. Combined with the practice, adaptive filtering is used in this experiment to filter OFDM signals.

3-3-2 Original OFDM Signal Simulation Results

Figure 5, 6 shows our simulation results of single OFDM signal in single channel or multi-channel. The simulation results are changed from binary digital baseband signal to quaternary signal through 16QAM modulation and gray code mapping, and then obtained by IFFT transformation.

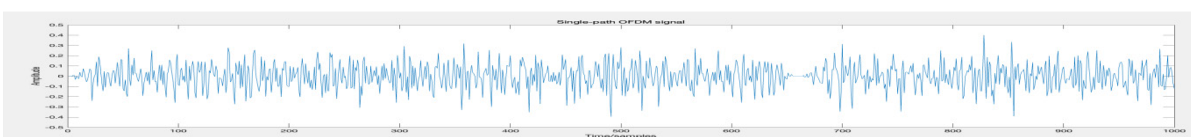

Figure 5. Single channel OFDM signal

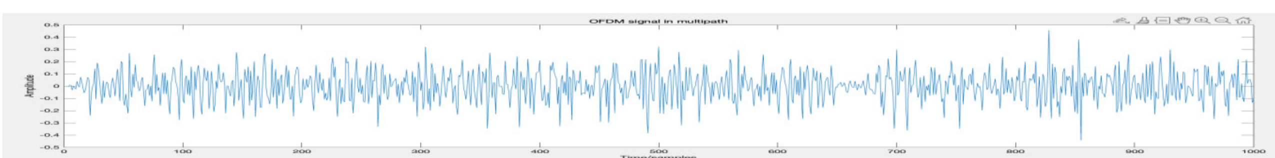

Figure 6. Multichannel OFDM signal

3-3-3 Constellation Diagram and Bit Error Rate Experiment of Received Signal in Single-path/Multi-path

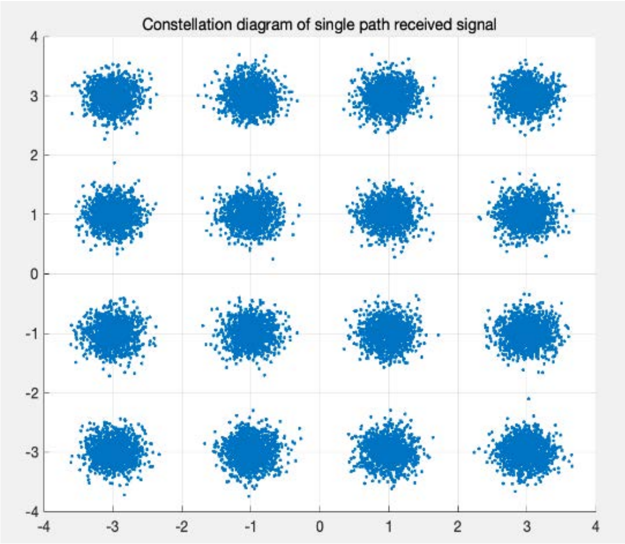

Figure 7. Constellation diagram of received signal in single path

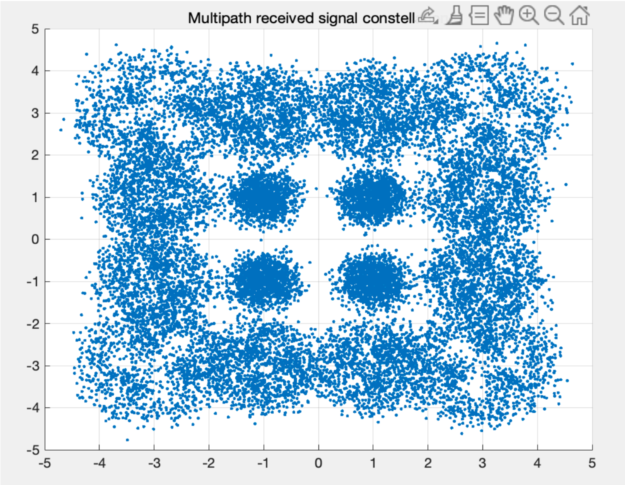

Figure 8. Constellation diagram of received signal in multi-path

By comparing the constellation diagram of received signals in a single path and that of a multi-path, as displayed in Figure 7, we can clearly see signals under a single path and multi-path are aliasing compared with those in a single path.

```
rate =

         0    0.0183
```

Figure 9. Bit error rate for single and multipath

Figure 9 shows bit error ratio of single path and multi-path channels. Bit error ratio of single-path channels is 0, while that of multi-path channels is 0.0183. Combined with Figures 7 and 8, we can seen OFDM has a very low bit error rate in single-path, and bit error rate in multi-path is a little more than bit error rate in single-path channels.

3-3-4 Simulation Experiment of Convergence Curve of LMS Algorithm

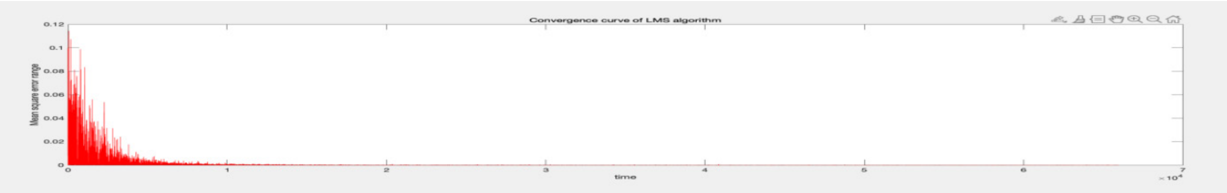

Figure 10. Convergence curve of LMS algorithm

As can be seen from Figure 10 of the simulation experiment results, the mean square error decreases rapidly as time goes on, which indicates the rapid improvement of the system performance, that is, the LMS algorithm reduces the error in a short time. When the time length reaches a fixed point, the mean square error gradually tends to a stable low level, which means that the system has reached a steady state.

3-4 Simulation Result Analysis

In the process of simulating OFDM, we introduced two assistive techniques, namely, cyclic prefix and cyclic suffix as well as adaptive filtering with LMS algorithm. At the same time, single-path and multi-path channels are used in the simulation process. Its results indicate that the

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bit error rate of OFDM in single-path is quite low, while that in multi-path is a little more compared with that in single-path. Thus, it can reduce the adverse influence of multi-path impact on the signal.

4. Suggestions

4.1 Optimization Algorithm

Improved LMS algorithm: Although LMS algorithm is advantageous with lower computational complexity, its convergence rate may be slow. Variants of LMs-based algorithms, such as NLMS or RLS algorithms, can be studied to improve convergence speed and stability.

4.2 Hardware Realization and Real-time Optimization

Hardware accelerator design: Research on hardware implementation schemes based on FPGA or ASIC can significantly improve the execution speed of LMS algorithm to meet the needs of real-time usages.
Low-power design: In hardware implementation, consider low-power design to extend the battery life of wireless devices, especially in mobile devices.

4.3 Multi-antenna System Expansion

Application in MIMO-OFDM system: The interference cancellation technology based on LMS is extended to MIMO-OFDM system to improve the performance of spatial multiplexing and enhance the anti-interference ability of the system.

4.4 Environment Awareness Combined with Machine Learning

Introducing machine learning techniques: It is possible to investigate how machine learning algorithms, like neural networks and reinforcement learning, can be combined with LMS algorithms to enhance the environment awareness of the system so that it can better predict and adapt to different channel conditions.
Real-time environment feedback mechanism: The development of real-time channel state feedback mechanism enables the system to dynamically adjust filter parameters to better cope with the rapidly changing environment.

5. Conclusion

5.1 Major Findings

The application of adaptive interference cancellation technology based on LMS algorithm in OFDM systems shows significant potential, especially when dealing with complex and dynamically changing wireless environments. By optimizing algorithms, combining advanced machine learning techniques, and implementing efficient adaptive processing on hardware, together with further improved performance of OFDM systems. Our future research direction should focus on improving its convergence speed, enhancing the real-time stability of the system, and exploring a wider range of application scenarios, such as multi-antenna systems and collaborative communication, for the purpose of comprehensively improving the anti-interference ability and communication quality of this system.

5.2 Limitations

Our simulation does not fully consider the hardware implementation of the filter, and the optimization degree of the filter performance in different environments is limited. Although the adaptive interference cancellation based on the LMS algorithm is able to enhance the performance of the OFDM system to a certain extent, it still has limitations in convergence speed, processing complex environments, computational complexity, and real-time performance. For the purpose of overcoming such limitations, it may be necessary to combine other more advanced algorithms or to improve and optimize the algorithm to meet the needs of different application scenarios.
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Haocheng Yu, Zhilin Yang and Yuliang Lin contributed equally to this work and should be considered co-first authors.

References

[1] Almutairi, A.F., Krishna, A. Filtered-orthogonal wavelet division multiplexing (F-OWDM) technique for 5G and beyond communication systems. Sci Rep 12, 4607 (2022). https://doi.org/10.1038/s41598-022-08248-3
[2] Vishwaraj and L. Ali, “Hybrid MIMO-OFDM System for 5G Network Using VLC-A Review,” 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, India, 2019, pp. 1-5, doi: 10.1109/ICECCT.2019.8869299.
[3] Ramteke S. B., Deshmukh A. Y. and Dekate K. N., “A Review on Design and Analysis of 5G Mobile Communication MIMO System with OFDM,” 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, 2018, pp. 542-546, doi: 10.1109/ICECA.2018.8474695.
[4] Garcia Armada, A. “Understanding the effects of phase noise in orthogonal frequency division multiplexing (OFDM),” in IEEE Transactions on Broadcasting, vol. 47, no. 2, pp. 153-159,

June 2001, doi: 10.1109/11.948268.
[5] Abuabed, A.S.A. Performance of Differential-Phase OFDM Systems over Selective Multipath Fading Channels. Electronics 2017, 6, 66. https://doi.org/10.3390/electronics6030066
[6] Shahzad, K., Wang, R. & Jamshid, J. A novel approach to geometric algebra-based variable step-size LMS adaptive filter algorithm. SIViP 18 (Suppl 1), 837–846 (2024). https://doi.org/10.1007/s11760-024-03196-z
[7] Ferrara, E. "Fast implementations of LMS adaptive filters," in IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 28, no. 4, pp. 474-475, August 1980, doi: 10.1109/TASSP.1980.1163432.
[8] Sireesha, N., Chithra, K. and Sudhakar, T., "Adaptive filtering based on least mean square algorithm," 2013 Ocean Electronics (SYMPOL), Kochi, India, 2013, pp. 42-48, doi: 10.1109/SYMPOL.2013.6701910.