Research on Digital Simulation of Blind Equalization in Multipath Ground-to-Air Communication Channel

Xilei Wu
College of Computer Science and Electronic Engineering, Hunan University, Tianma Student Apartment, Juzizhou Street, Yuelu District, Changsha, Hunan.
Email:1403839770@qq.com

Abstract. In ground-to-air communication, the inter-symbol interference caused by multipath effect is often the important cause of poor communication quality. Channel equalization technology can effectively solve the problem of inter-symbol interference in ground-to-air communication. Firstly, we theoretically analysed the multipath transmission channel of ground-to-air communication and did the simulation modeling work. Then, we selectively analysed the model structure, the principle of the process and the adopted key equalization algorithm. Based on the technology system and working parameters commonly used in ground-to-air communication, we simulated equalizing reception processing performance of the communication model in multipath channel and gave some simulation data. Experimental results showed that DD-LMS adaptive equalization technology can significantly improve the reception performance of the communication system in the ground-to-air communication system which is affected by multipath interference and it provides valuable reference for the evaluation of the multipath transmission performance of the ground-to-air communication system.

1. Overview
Generally, it is hard to convey data under ideal conditions in wireless communication, especially in ground-to-air communication. And inter-symbol interference caused by multipath becomes worse with the increasing transmission rate, leading to serious influence to the quality of communication. Channel equalization technology can effectively solve the problem of signal interference in ground-to-air communication and improve the quality of data transmission. Channel equalization technology includes traditional adaptive equalization and blind equalization. In some special situations, traditional adaptive equalization takes up limited channel resources due to the need of training sequence of channel transmission, reduces the utilization rate of channel and data transmission efficiency and extends the time of information transmission and processing, which limits its use. The blind equalization technology can make use of the received signals to calculate the characteristics of ground-to-air communication channel and adjust filter parameters to equalize the channel, so as to solve the problems of high channel resource consumption and low transmission efficiency in traditional adaptive equalization, thereby being applied effectively in the ground-to-air communication environment in which the data rate is continuously improved.
2. Construction of Ground-to-Air Communication Channel Transmission Model

In the multipath ground-to-air communication environment, when baseband signal is processed by equalization technique at receiver end, the transmission model of multipath wireless communication channel is shown in Figure 1.

In Figure 1, d(k) is the signal output by the transmitter at the time t=k, which is expressed in the form of digital sequence. The sequence is output through shaping filtering and carrier modulation at the transmitter end, and the sequence signal d(k) is modulated on the radio frequency (RF) carrier f_c in a certain way.

\[
s(t) = A_c d(t) \cos(2\pi f_c t + \theta_c)
\]

In formula (1), \(A_c\) is the carrier amplitude, \(f_c\) is the carrier frequency, \(\theta_c\) is the initial phase of the carrier and \(d(t)\) is the NRZ (non-return to zero) code stream formed after the code type transformation of the sending sequence.

\(G_m\cdot s(t-\tau_m)\) is the signal components (except the main signal component) of modulated signal \(s(t)\) transmitted to the receiver input through \(m\) paths. \(\tau_m\) is time delay of each multipath signal relative to the main signal component. And \(G_m\) is the fading factor of each multipath signal in the process of signal transmission.

\(h(t)\) represents the equivalent impulse response of the direct channel. \(h(t-\tau_m)\) represents the equivalent impulse response of multipath channel.

\(n(t)\) is the external input noise, which generally refers to AWGN (additive white gaussian noise).

At the receiver end, the received input signal \(r(t)\) is expressed by the following formula, which is shown as

\[
r(t) = s(t) + \sum_{i=1}^{\infty} G_{m}(i) s(t-\tau_m) + n(t)
\]

The demodulated output signal of the receiver is the digital baseband signal, and the digital baseband signal reaching the input end of the equalizer is represented by \(x(k)\). After passing the modulation and demodulation link of the wireless communication system, \(x(k)\) is expressed as formula (3) in the numeric field.

\[
x(k) = h(k) \ast d(k) + \sum_{m=1}^\infty G_m \left[ h(k-\tau_m) \ast d(k-\tau_m) \right] + n(k)
\]

\[
= \sum_{i=1}^{k-1} h(i) \ast d(k-i) + \sum_{m=1}^\infty \sum_{i=1}^{k-1} G_m \left[ h(\tau_m+i) \ast d(k-\tau_m-i) \right] + n(k)
\]

In the equation above, \(\ast\) is the convolution symbol and \(\cdot\) is the product symbol. \(w(k)\) is the impulse response of the equalizer, which is generally realized by transversal filter (FIR). \(y(k)\) is the output sequence of the equalizer, which is expressed as
In formula (4), \( w(k) = [w_0(k), w_1(k), w_2(k), ..., w_{J-1}(k)]^T \) is represented by vector \( W_k \) which represents the tap weight vector of equalizer with order \( J \).

If the input vector of the equalizer is expressed in terms of \( X_k \), then \( X_k \) is expressed as

\[
X_k = [x(k), x(k-1), x(k-2), ..., x(k-J+1)]^T
\]

(5)

3. Model Analysis of Blind Equalization Algorithm

There are many blind equalization algorithms with their own characteristics. In this paper, we used an adaptive equalization algorithm based on DD-LMS (Decision Directed-Least Mean Square) to model and simulate the equalizer. Relatively speaking, this algorithm has a faster convergence rate than the constant modulus algorithm and other multi-mode algorithms, but it may lead to the cost of reduced reliability caused by equilibrium failure when the eye graph is closed [4-8]. DD-LMS algorithm equalizer model is shown in figure 2.

![Equalizer model of DD-LMS algorithm](image)

In figure 2, \( x(k) \) is the input sequence of the equalizer, \( W^* \) is the tap weight vector of the transversal filter. The filter output \( y(k) \) goes into decision \( g(\cdot) \), and the decided outputs are processed in the following formula

\[
\hat{d}(k) = \text{sgn}\left[\tilde{d}(k)\right]
\]

(6)

In formula (6), \( \hat{d}(k) \) is the estimation of the signal source \( d(k) \) in figure 1, and \( \tilde{d}(k) \) is corresponding to

\[
y(k) = \begin{cases} +1 & \text{symbol '1'} \\ -1 & \text{symbol '0'} \end{cases}
\]

(7)

Then, the guiding error signal \( e(k) \) is

\[
e(k) = d(k) - \tilde{d}(k)
\]

(8)

Tap gain adjustment algorithm uses the cost function \( J_{DD-LMS}(k) \) to adjust the tap coefficient of the transversal filter. \( J_{DD-LMS}(k) \) is expressed as

\[
J_{DD-LMS}(k) = E\left[\frac{1}{2}e^2(k) + r\|w(k)\|^2\right]
\]

(9)

In formula (9), \( r \) is the leakage coefficient, \( 0 \leq r < 1 \).
The gradient of $J_{DD-LMS}(k)$ needs to be calculated. And then the minimum value of the cost function $J_{DD-LMS}(k)$ is calculated through iteration. When the cost function reaches the minimum value, the weight of the equalizer tends to be stable and optimal. The gradient calculation of $J_{DD-LMS}(k)$ is expressed as

$$\frac{\partial J_{DD-LMS}(k)}{\partial W_k} = rw(k) - e(k)x^*(k)$$ \hspace{1cm} (10)$$

Tap coefficient is calculated by tap gain adjustment algorithm, and the transversal filter outputs tap coefficient vector $W_k^*$. The blind equalization adaptive algorithm is expressed as

$$w(k+1) = (1 - r \cdot \mu)w(k) - \mu e(k)x^*(k)$$ \hspace{1cm} (11)$$

In formula (11), symbol '$^*$' represents conjugate, and symbol '$\mu$' represents step size factor.

4. Simulation and Result Analysis

4.1 Simulation Environment and Related Parameters

The simulation model is established in accordance with figure 1, and the equalizer model is shown in figure 2. According to this model, the simulation circuit is built in the System Vue environment. Table 1 shows the main parameters.

| Type          | Data rate $R_b$(Mbps) | Carrier $f_c$(GHz) | Modulation system | Number of multipath                | Parameters of equalizer       |
|---------------|-----------------------|--------------------|-------------------|-------------------------------------|-------------------------------|
| Parameters    | 1.024                 | 1.6                | PSK               | 1 path of main signal; 1 path of multipath signal (fading factor $G_m$ changeable); changeable time delay $\tau_m$; determined initial phase $\phi_m$ | Step size $\mu$=0.4; Leakage coefficient $r$=0; Number of filter tap $J$=10 |

There are many paths of multipath signal components in the ground-to-air communication environment. It is impossible to list them all. And usually the strongest multipath signal component has the greatest influence on transmission performance. In addition to changes of amplitude $A_1$ (or signal strength $P_1$) of this multipath signal, changes of transmission delay $\tau_1$ and random changes of carrier phase $\phi_1$ influenced by multipath channel will both have an effect on the quality of the received signal. To simplify the complexity of the simulation, the simulation is set in environment which only includes 1 path of main signal and 1 path of the strongest multipath signal component. By adjusting the multipath signal fading factor $G_1$ and its transmission delay $\tau_1$ ($\tau_1$ indirectly changes phase), the paper shows part of the simulation data.

4.2 Simulation Results and Analysis

Figure 3- Figure 11. shows the simulation curve graph when value of $G_1$ is set to -3 dB, -6 dB, -12 dB respectively and $\tau_1$ is set to 0.5 $T_b$, 1.5 $T_b$, 2.5 $T_b$ ($T_b = 1/R_b$) respectively. These graphs present contrast figures of input and output signals of the equalizer under different fading factor $G_1$ and time delay $\tau_1$, convergence curve graphs of error and eye patterns of baseband signals before and after equalization.
Figure 3. Simulation experiment curve graph when $G_t = -3 \text{ dB}$, $\tau_i = 0.5T_b$

Figure 4. Simulation experiment curve graph when $G_t = -3 \text{ dB}$, $\tau_i = 1.5T_b$

Figure 5. Simulation experiment curve graph when $G_t = -3 \text{ dB}$, $\tau_i = 2.5T_b$
Figure 6. Simulation experiment curve graph when $G_l = -6$ dB, $\tau_1=0.5T_b$

Figure 7. Simulation experiment curve graph when $G_l = -6$ dB, $\tau_1=1.5T_b$

Figure 8. Simulation experiment curve graph when $G_l = -6$ dB, $\tau_1=2.5T_b$
Figure 9. Simulation experiment curve graph when $G_I = -12$ dB, $\tau_1 = 0.5T_b$

Figure 10. Simulation experiment curve graph when $G_I = -12$ dB, $\tau_1 = 1.5T_b$

Figure 11. Simulation experiment curve graph when $G_I = -12$ dB, $\tau_1 = 2.5T_b$

According to the simulation process and the data shown in figure 3 – figure 11, the analysis shows that when the multipath fading factor remains unchanged, the opening extent of eye pattern before
equalization will be seriously influenced by multipath time delay. With the increase of multipath time delay, the quality of eye pattern deteriorates accordingly. When the multipath delay is within $0.5T_s \sim 1T_s$, eye pattern deteriorates significantly. As the multipath delay increased by $1T_s$, the deterioration gradually becomes more significant. When multipath time delay remains the same, the quality of the eye pattern is in an open state, the quality of received signal can be significantly improved after being processed by DD-LMS equalization algorithm, so as to achieve the purpose of restoring the received signal quality. With DD-LMS algorithm, the steady-state tracing error of DD-LMS algorithm will increase with the increase of multipath fading factor, but will not be greatly affected by the variation of multipath time delay.

5. Concluding Remarks
In this paper, the theoretical and simulated model of ground-to-air communication multipath transmission channel is established, and the principle analysis of the established model and the core equalization algorithm is carried out. The equalization reception and processing performance of the multipath transmission channel is simulated by combining common technical system and working parameters, and some simulation test data are given. Experiment results show that DD-LMS adaptive equalization technology can significantly improve the reception performance of the communication system which is seriously affected by multipath interference, providing valuable reference for the evaluation of the multipath transmission performance of the ground-to-air communication system.

6. Reference
[1] Liu Xu, Xie Laiyang. Research on multipath interference of VHF ground-to-air communication in civil aviation [J]. Journal of mass technology, 2014(10):43-45.
[2] Guo Rifeng. Research on multipath fading in navigation channel of air communication [D]. Xi ‘an dianzi university. 2010.
[3] Ma Xiaoyu, Hu Jianwei. Research and development of blind equalization technology [J]. China new communications,2009(10):73-75.
[4] Li Xinxin, Chang Shuai, Li Hong. Comparison and simulation of several blind equalization algorithms [J]. Electronic design engineering,2012,20(1):63-66.
[5] Ouyang Xi, Ge Lindong. A new CMA blind equalization algorithm based on data reliability decision-directed [J]. Journal of communications,2001, 22(5):125-128.
[6] Liu Feng and Ge Lindong. Research on blind equalization algorithm based on decision feedback equalizer structure. Journal of information engineering university, 2004,5(3):78-81
[7] S.J. Nowlan and G.E. Hinton. A soft decision-directed LMS algorithm for blind equalization [J]. IEEE Trans. Commun., vol. 41, no. 2, pp. 275 - 279, Feb. 1993.
[8] J. Yang. Multimodulus algorithms for blind equalization [D]. Ph. D. Dissertation, Univ., British Columbia, than, BC, Canada,. 1997.