Research on Iterative Receiving Algorithm for Aviation Communication System

Di Wang, Sheng Wu, Yuehong Gao, Lin Sang
School of information and communication engineering
Beijing University of Posts and Telecommunications
Beijing, P.R. China, 100876
Email: wangdibupt@bupt.edu.cn

2020 IEEE 19th International Conference on Cognitive Informatics & Cognitive Computing (ICCI*CC) | 978-1-7281-9594-0/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICCICC50026.2020.9450266

***Abstract*—To cope with the growth of traffic and the need for high-speed transmission, the next-generation aviation communication technology considers deploying the L-bond digital aeronautical communication system (L-DACS1) based on orthogonal frequency division multiplexing (OFDM) in ground-to-air scenarios. But the aviation channel with strong multipath, long-distance, Doppler frequency shift and other characteristics is likely to cause severe channel fading, which affects the reliability of the system and requires channel equalization. At present, the traditional one-time equalization algorithms are generally used in the research of channel equalization in aviation communication systems, but the performance is not ideal. This paper firstly introduces the idea of iteration to the aviation communication system, proposes to use SISO (soft input soft output) equalizer and SISO decoder at the receiving end, and design the iterative receiving algorithm of joint equalization and decoding to realize signal reception. After an in-depth study of linear minimum mean square error (LMMSE) algorithm and Gaussian approximate message passing (AMP-G) algorithm, simulations were built to analyze system performance. The results show that both algorithms can significantly reduce the bit error rate, improve the system reliability, obtain 0.6 dB gain through iteration, save receiver power, and increase the flight radius. The iterative receiving algorithm can improve flight safety, optimize user experience in civil systems, and resist interference, increase the combat range in military systems, so it has broad applications.**

Keywords*—aviation channel, iterative receiver, L-DACS1 system, LMMSE algorithm, AMP-G algorithm.

I. Introduction

At present, the 5th generation mobile networks (5G) are developing rapidly and are gradually being commercialized on a large scale. The 5G system introduces technologies such as non-orthogonal multiple access, massive MIMO, D2D communication, ultra-dense networking, and co-frequency co-time full duplex to cope with multi-dimensional capability indicators such as high speed, low latency, ultra-high traffic, and numerous connections [1]. In contrast, the development of aviation communication systems is relatively slow.

In 1947, ICAO deployed the aeronautical communication system at Very High Frequency (VHF), adopted bilateral band amplitude modulation, and completed standardization. In 1979, the frequency band was expanded to 117.975 MHz to 137.000MHz. This narrow-band ground-to-air communication system has been used until now [2]. However, as air traffic and communication needs continue to expand, the old technical system is hard to support the development of the aviation communication industry. It is predicted that aviation channel capacity will become saturated, and the VHF band will become more congested [3]. Therefore, the European and American aviation administration proposed to deploy the L-bond digital aeronautical communication system (L-DACS1) in the ground-to-air scenario in the future aviation communication system. The L-DACS1 system uses cascade code, FDD-OFDM, and a variety of modulation methods, which has high spectrum utilization and robust scalability. However, combined with the characteristics of narrow-band, high-speed, strong multipath, wide coverage, and Doppler frequency shift of the aviation channel, the OFDM-based L-DACS1 system is prone to severe channel fading, which affects system reliability. The current general solution is to use the traditional one-time equalization algorithm, but the performance is not ideal. There are problems such as insufficient bit error rate affecting the effective command of the tower, high complexity of the algorithm, inadequate power consumption of the airborne receiver limiting the flight radius, and high risk caused by interference from the avionics system. In order to overcome aeronautical channel fading, high-performance airborne receivers need to be designed to ensure the transmission rate and reliability of the communication system.

At present, there are relatively mature researches on the traditional channel equalization of aviation communication systems. The problems of high out-of-band power, high up-down conversion complexity, high peak-to-average ratio, and large frequency deviation caused by the use of OFDM in aviation communication systems were studied [2]. Literature [4] studied a variety of traditional equalization algorithms, such as linear equalization, maximum likelihood sequence detection equalization, and decision feedback equalization, which is applied to the aeronautical channel and has excellent anti-multipath performance but not ideal bit error performance at high symbol rates. In the single-carrier aviation communication system, the time-domain equalization scheme for interference cancellation is designed in [5]. However, due to the limitation of the single-carrier system, as the channel delay spread increases, the complexity of the equalizer also increases. The iterative receiving algorithms of joint equalization and decoding based on the soft decision are studied in [6]-[10]. The method of expressing the message passing process with a factor graph is used to design the iterative receiver and is analyzed in a MIMO-OFDM system in [6]. The expressions of the Linear Minimum Mean Square Error (LMMSE) algorithm in the time and frequency domains are simplified in [7],[8]. The Gaussian Approximate Message Passing-Gaussian (AMP-G) algorithm based on brief propagation is applied to 3D massive MIMO systems and exhibits excellent performance [9],[10]. Compared with general receivers, iterative receivers have apparent advantages in terms of bit error rate and complexity by designing the receiving algorithm and iteratively processing the soft information output by the decoder.

2020 IEEE 19th Int'l Conf. on Cognitive Informatics & Cognitive Computing (ICCI*CC'20)
Y. Wang, N. Ge, J. Lu, X. Tao, P. Soda, N. Howard, B. Widrow, & J. Feldman (Eds.)
978-1-7281-9594-0/20/$31.00 ©2020 IEEE

In this paper, the characteristics of multipath delay and Doppler frequency shift in the aviation channel are modeled to construct the aviation communication scenario in the L-DACS1 system. The concatenated code is replaced with LDPC code which has stronger decoding performance and burst error correction capability to optimize channel coding. We derive the LMMSE and AMP-G algorithms and use them to design iterative receivers to realize joint equalization and decoding, and establish link-level simulations to analyze the system performance. The results show that the iterative receiving algorithm can improve the aviation communication system's performance in terms of anti-multipath, anti-Doppler shift and saving receiver power.

II. SYSTEM MODEL AND ITERATIVE RECEIVER

In the ground-to-air communication scenario of the L-DACS1 system, the channel can be modeled as a Wide Sense Stationary Uncorrelated Scattering (WSSUS) channel according to the time-varying characteristics of the aviation channel. This paper discusses the downlink signal transmission of the aircraft in the cruise scenario. In this scenario, the aviation channel can be modeled as the two-path Rice channel shown in Figure 1, including a direct path Los and a reflection path R. The flying height of the aircraft is $h = 10\ \mathrm{km}$. The coverage radius is $l = 370\ \mathrm{km}$. The flying speed is $v = 440\ \mathrm{m \cdot s^{-1}}$. The minimum incident wave arrival angle is $\phi_{\mathrm{al}} = 178.25°$, and the maximum incident wave arrival angle is $\phi_{\mathrm{ah}} = 181.75°$. The maximum transmission delay is $\tau_{\max} = 33\ \mu\mathrm{s}$. The Rice factor is $K = 20\ \mathrm{dB}$. There is a transmitting antenna at the tower end and two receiving antennas at the aircraft end to form a 1×2 MIMO system.

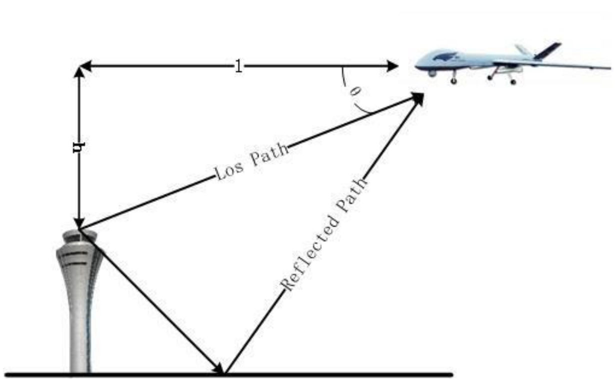

Fig. 1. Two-path model in cruise scenario.

According to the expression of the WSSUS multipath time-varying channel, the channel impulse response expression of the aviation channel can be obtained [11]:

$$
\begin{aligned}
h(t,\tau) = a \cdot e^{j2\pi f_{DLos} t} \sigma\left(\tau - \tau_0\right) \\
+ c \cdot e^{j\theta_R} e^{j2\pi f_R t} \sigma\left(\tau - \tau_{\max}\right)
\end{aligned}
\tag{1}
$$

Where f_{DLos} is the Doppler frequency shift of the direct path, f_{R} is the Doppler frequency shift of the reflected path, and θ_{R} is the initial phase of the reflected path. Considering the relative delay $\tau_0 = 0$. a and c are the amplitude of the direct path and the reflected path, respectively satisfying $a = \sqrt{\dfrac{K}{K+1}}$, $c = \sqrt{\dfrac{1}{K+1}}$. Using the Monte Carlo method to find the Doppler frequency shift and phase in equation (1) to generate a uniform distribution $u_n \in [0,1]$, we can get:

$$
f_{\mathrm{D}n} = f_{\mathrm{DMax}} \cos\left(\phi_{\mathrm{al}} + \left(\phi_{\mathrm{ah}} - \phi_{\mathrm{al}}\right) \cdot u_n\right) \tag{2}
$$

$$
p\left(\theta_n\right) = \frac{1}{2\pi} \quad 0 \le \theta_n \le 2\pi \tag{3}
$$

Where $f_{\mathrm{D}n}$ represents the Doppler frequency shift of the nth path in the aviation channel, $f_{\mathrm{DMax}} = f_c \dfrac{v}{c} \cos\theta$ represents the maximum Doppler frequency shift, the carrier frequency f_{c} is 3.9 GHz, and equation (3) is the probability density function of the phase, indicating that the phase is evenly distributed within $[0, 2\pi]$. At this point, the physical channel modeling is completed.

Processing in the digital domain requires the discretization of the channel. Refer to the discretization method for linear time-varying physical channels in [12]. For the under-expanded channel with microsecond delay of the aviation channel, we equate the channel to a baseband model and use the sampling theorem to perform discretization, obtaining the equivalent baseband discrete channel shown in formulas (4) and (5):

$$
y[m] = \sum_{l} h_l[m] x[m-l] \tag{4}
$$

$$
\begin{aligned}
h_l[m] = a \cdot e^{j2\pi f_{DLos} \frac{m}{W}} \operatorname{sinc}(l) \\
+ c \cdot e^{j\theta_R} e^{j2\pi f_R \frac{m}{W}} e^{-j2\pi f_c \tau_{\max}} \sin c\left(l - \tau_{\max}\right)
\end{aligned}
\tag{5}
$$

We consider the model of the entire communication link. At the transmitter in the tower, the information bits $\mathbf{i}$ are encoded into the LDPC sequence and interleaved, yielding a code sequence $\boldsymbol{c}$. The code $\boldsymbol{c}$ is divided by length-Q subsequence $\left\{\boldsymbol{c}_n = \left[c_{n,1}, c_{n,2}, \ldots, c_{n,Q}\right]^T\right\}$. Through modulation and mapping $\mathcal{M}: \{0,1\}^Q \to \mathcal{X}$, we can get the symbol sequence $\boldsymbol{x}$, where $\mathcal{X} = \left\{\alpha_i, i = 1, 2, \ldots, 2^Q\right\}$ denotes a symbol alphabet with $\sum_{i=1}^{2} \alpha_i = 0$ and $2^{-Q} \sum_{i=1}^{2^Q} \left|\alpha_i\right|^2 = 1$, and each element α_i corresponds to a binary vector $\boldsymbol{s}_i = \left[s_{i,1}, s_{i,2}, \ldots, s_{i,Q}\right]^T$. We use OFDM as the waveform. The received signal vector $\boldsymbol{z}$ can be modeled as:

2020 IEEE 19th Int'l Conf. on Cognitive Informatics & Cognitive Computing (ICCI*CC'20)
Y. Wang, N. Ge, J. Lu, X. Tao, P. Soda, N. Howard, B. Widrow, & J. Feldman (Eds.)
978-1-7281-9594-0/20/$31.00 ©2020 IEEE

$$z = Hx + w \tag{6}$$

Where $\boldsymbol{H}$ represents the aviation channel matrix converted from formula (5). Although the aviation channel is a complex time-varying channel, it can be considered that the channel remains unchanged during each OFDM symbol time. $\boldsymbol{w}$ indicates additive complex Gaussian white noise, which is independent and obeys $\mathcal{CN}\left(\boldsymbol{w};\boldsymbol{0},2\sigma^2\boldsymbol{I}\right)$. The decoder outputs a priori log-likelihood ratio (LLR), and the SISO equalizer calculates the external LLR by the following formula (7)

$$L^e\left(c_{n,q}\right) = \ln\frac{P\left(c_{n,q}=0\,|\,\mathbf{z}\right)}{P\left(c_{n,q}=1\,|\,\mathbf{z}\right)} - L\left(c_{n,q}\right) \tag{7}$$

Iteratively adjust the external LLR, and use the final output external LLR for decoding decision to complete the iterative reception. In summary, the system transmission process is shown in Figure 2

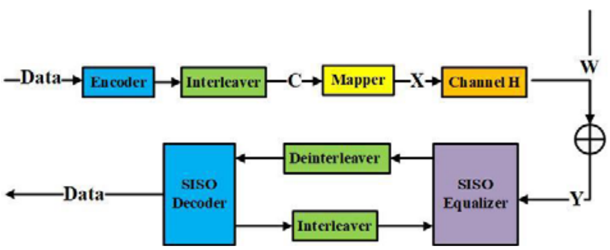

Fig. 2. Aviation communication system transmission flow chart

III. Iterative Receiving Algorithm

Inspired by the iterative decoding of Turbo codes, the communication industry proposes a turbo equalization system with joint equalization and decoding, continuously exchanging the external information of the equalizer and decoder through iterations, thereby obtaining a lower bit error rate.

In order to overcome the aeronautical channel fading, this paper proposes adopting the iterative receiving algorithm to the aviation channel. It is expected to reduce the algorithm complexity and receiver power consumption and increase the flight radius while ensuring the performance of the bit error rate.

A. Simplified LMMSE algorithm

Consider the system model given by formula (6), assuming that the information bits x_n has PDF $\mathcal{CN}\left(x_n;m_n,v_n\right)$. Therefore $\boldsymbol{x}=[x_1,x_2,...,x_N]$ has PDF $\mathcal{CN}\left(\boldsymbol{x};\boldsymbol{m},\boldsymbol{V}\right)$, where $\boldsymbol{m}=[m_1,m_2,...,m_N]^T$ and $\boldsymbol{V}=diag[v_1,v_2,...,v_N]$. Since $\boldsymbol{w}$ is a complex Gaussian random variable obeyed $\mathcal{CN}\left(\boldsymbol{w};\boldsymbol{0},2\sigma^2\boldsymbol{I}\right)$, for the received $\boldsymbol{z}$, $p(\boldsymbol{z})$ is a constant. It can be derived by Bayesian formula:

$$\begin{aligned} p(\boldsymbol{x}\,|\,\boldsymbol{z}) &= \frac{p(\boldsymbol{xz})}{p(\boldsymbol{z})} \\ &= \frac{p(\boldsymbol{z}\,|\,\boldsymbol{x})\bullet p(\boldsymbol{x})}{p(\boldsymbol{z})} \\ &\propto p(\boldsymbol{z}\,|\,\boldsymbol{x})\bullet p(\boldsymbol{x}) \end{aligned} \tag{8}$$

Where $p(\boldsymbol{z}\,|\,\boldsymbol{x})$=$\mathcal{CN}\left(\boldsymbol{z};\boldsymbol{Hx},2\sigma^2\boldsymbol{I}\right)$ and $p(\boldsymbol{x})$ are known. In this way, the posterior probability of $\boldsymbol{x}$ is converted into the form of multiplication of two complex Gaussian probability density functions. Expand the Gaussian probability density function and compare the coefficients, we can get [7]:

$$p(\boldsymbol{x}\,|\,\boldsymbol{z}) = \mathcal{CN}\left(\boldsymbol{x};\boldsymbol{m}^p,\boldsymbol{V}^p\right) \tag{9}$$

Where,

$$\boldsymbol{m}^p = \boldsymbol{m} + \frac{1}{2\sigma^2}\boldsymbol{V}^p\boldsymbol{H}^H(\boldsymbol{z}-\boldsymbol{Hm}) \tag{10}$$

$$\boldsymbol{V}^p = \left(\boldsymbol{V}^{-1} + \frac{1}{2\sigma^2}\boldsymbol{H}^H\boldsymbol{H}\right)^{-1} \tag{11}$$

Therefore,

$$\boldsymbol{V}^p = \left(\boldsymbol{V}^{-1} + \frac{1}{2\sigma^2}\boldsymbol{H}^H\boldsymbol{H}\right)^{-1} \tag{12}$$

Due to the matrix inversion in formula (11), the inverse matrix needs to be guaranteed not to be a singular matrix during each Turbo iteration. Simplify the external LLR defined by equation (7) with Bayesian formula, and we can get formula (13):

$$L^e\left(c_{n,q}\right) = \ln\frac{\sum_{\alpha_i\in\mathcal{X}_q^0} p\left(z\,|\,x_n=\alpha_i\right)\prod_{q'\neq q} P\left(c_{n,q'}=s_{i,q'}\right)}{\sum_{\alpha_i\in\mathcal{X}_q^1} p\left(z\,|\,x_n=\alpha_i\right)\prod_{q'\neq q} P\left(c_{n,q'}=s_{i,q'}\right)} \tag{13}$$

So we can get the prior probability of each information bit:

$$p\left(z\,|\,x_n\right) = p(z)\frac{p\left(x_n\,|\,z\right)}{p\left(x_n\right)} = \mathcal{CN}\left(x_n;m_n^e,v_n^e\right) \tag{14}$$

Where,

$$v_n^e = \left(\frac{1}{v_n^p} - \frac{1}{v_n}\right)^{-1} \tag{15}$$

$$m_n^e = v_n^e\left(\frac{m_n^p}{v_n^p} - \frac{m_n}{v_n}\right) \tag{16}$$

Substituting formula (13), we can get the simplified expression of external LLR, as shown in formula (17).

$$L^e\left(c_{n,q}\right) = \ln\frac{\sum\limits_{\alpha_i\in\mathcal{X}_q^0}\exp\left(-\frac{\left|\alpha_i - m_n^e\right|^2}{v_n^e}\right)\prod\limits_{q'\neq q}P\left(c_{n,q'}=s_{i,q'}\right)}{\sum\limits_{\alpha_i\in\mathcal{X}_q^1}\exp\left(-\frac{\left|\alpha_i - m_n^e\right|^2}{v_n^e}\right)\prod\limits_{q'\neq q}P\left(c_{n,q'}=s_{i,q'}\right)} \tag{17}$$

In summary, the steps of the LMMSE iterative receiving algorithm are shown in Table 1:

TABLE I. SIMPLIFIED LMMSE ALGORITHM STEPS

LMMSE algorithm
（1）Initialize the external information bits $L^e = 0$.
（2）During each iteration
1. Calculate m_n, v_n with external information to get $\boldsymbol{m}, \boldsymbol{V}$.
2. Calculate $\boldsymbol{m}^p, \boldsymbol{V}^p$ with formula (10) (11).
3. Calculate m_n^e, v_n^e with formula (15) (16).
4. Calculate L^e with formula (17), and the obtained L^e is used for the next iteration calculation
（3）After the iteration is completed, the last external information is used for decoding

B. Iterative receiving algorithm based on AMP

In the iterative receiving process, the message passing process is often very complicated. Literature [7] studied the method of using a factor graph to represent the message passing process. The factor graph is a bidirectional graph, whose rule is to factorize a global function with multiple variables to obtain the product of several local functions, each function corresponds to a function node, each variable corresponds to a variable node, function nodes and corresponding variable nodes are connected by edges. The factor graph can be used to transform the iterative receiving process into a message passing process on the factor graph.

By using factor graphs to study iterative decoding, the industry has proposed many algorithms with excellent performance, of which Approximate Message Passing (AMP) has received widespread attention due to its outstanding performance. The design process of iterative receiving algorithm based on AMP is shown in Figure 3. Literature [10] proposed the AMP-G algorithm based on brief propagation and applied it to 3D massive MIMO scenario, showing excellent performance. In this section, the AMP-G algorithm is applied to the ground-to-air scenario, and the adaptive changes are made based on the characteristics of the aviation channel.

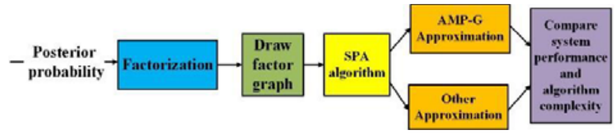

Fig. 3. AMP algorithm design flow chart.

The basic principle of the AMP-G algorithm first needs to process the posterior probability expression (18) of the information bits:

$$p\left(i_n \mid \boldsymbol{y}\right) \propto \sum\nolimits_{\boldsymbol{i}\setminus i_n,\boldsymbol{c},\boldsymbol{x}} \int_{\boldsymbol{W},\boldsymbol{h}} p(\boldsymbol{i},\boldsymbol{c},\boldsymbol{x},\boldsymbol{y},\boldsymbol{W},\boldsymbol{h}) \tag{18}$$

Where $\boldsymbol{h}$ represents the time-domain channel coefficient, and $\boldsymbol{W}$ represents the frequency-domain channel response. There is a corresponding relationship between them. Factoring the joint probability, we can get:

$$p(\boldsymbol{i},\boldsymbol{c},\boldsymbol{x},\boldsymbol{y},\boldsymbol{W},\boldsymbol{h}) = p(\boldsymbol{i})p(\boldsymbol{c}\mid\boldsymbol{i})p(\boldsymbol{x}\mid\boldsymbol{c})p(\boldsymbol{y}\mid\boldsymbol{W},\boldsymbol{x})p(\boldsymbol{W}\mid\boldsymbol{h})p(\boldsymbol{h}) \tag{19}$$

According to the law of factor graph, considering that the L-DACS1 system uses OFDM waveforms, combined with the two-path communication link of the aviation communication 1×2 MIMO system, we can draw the factor graph diagram as shown in Figure 4.

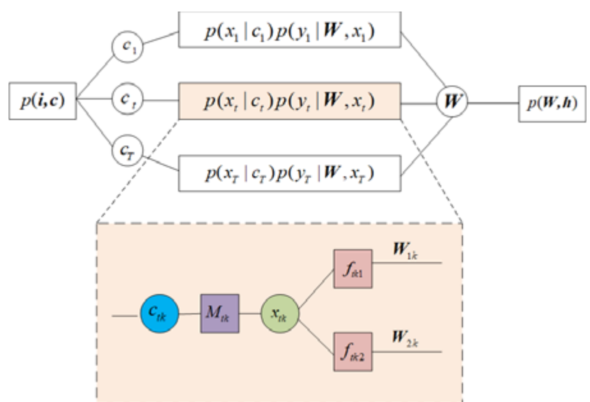

Fig. 4. AMP-G algorithm factor graph.

Where *T* represents the OFDM symbol number, *K* represents the subcarrier number, the node *M* represents the mapping constraint $p(x_{tk}\mid c_{tk})$, and node f represents the channel transfer function $p(\boldsymbol{y}\mid\boldsymbol{W},\boldsymbol{x})$. In each iteration, the sum-product algorithm (SPA) is used to update the probability expression of the variable nodes in the factor graph. Through continuous iteration, the external LLR expression of the information bit is calculated as:

$$L_e^{(i)}\left(c_{tk}^q\right) = \ln\frac{\sum\limits_{x_{tk}\in\mathcal{X}_q^1}\mu^{(i)}_{x_{tk}\to\mathcal{M}_{tk}}\left(x_{tk}\right)\mu^{(i-1)}_{\mathcal{M}_{tk}\to x_{tk}}\left(x_{tk}\right)}{\sum\limits_{x_{tk}\in\mathcal{X}_q^0}\mu^{(i)}_{x_{tk}\to\mathcal{M}_{tk}}\left(x_{tk}\right)\mu^{(i-1)}_{\mathcal{M}_{tk}\to x_{tk}}\left(x_{tk}\right)} - L_a^{(i-1)}\left(c_{tk}^q\right) \tag{20}$$

TABLE II. AMP-G ALGORITHM STEPS

AMP-G algorithm
(1) Initialize the external information bits $L^e = 0$.
(2) During each iteration
1. Under the Gaussian assumption, calculate the mean and variance of the information bit components in the received bits, and normalize through moment matching to obtain the message $\mu^{(i)}_{f_{tkl} \to x_{tk}}(x_{tk})$ passed from node f to node x.
2. Update messages from node x to node M with SPA algorithm [6].
3. Calculate bit extrinsic LLR according to formula (20).
4. Input the external LLR to the decoder, and the decoder outputs the prior LLR of the information bits, which is $L^{(i)}_a(c^q_{tk})$, and feeds it back to the mapping node M to obtain the message $\mu^{(i)}_{M_{tk} \to x_{tk}}(x_{tk})$.
5. Update message $\mu^{(i)}_{x_{tk} \to f_{tkl}}(x_{tk})$ using the SPA algorithm to complete a decoding iteration.
(3) After the iteration is completed, the last external information is used for decoding

IV. SIMULATION RESULTS AND ANALYSIS

According to the system model analyzed in section Ⅱ, link-level simulation is built by Matlab to complete the research on a two-path aviation channel and two iterative receiving algorithms in the aviation communication scenario. In the simulation, 8 OFDM symbols per frame are configured, and each OFDM symbol has 256 subcarriers, which are coded by LDPC. Every simulation takes a 100-bit error result as a valid error, and the maximum number of iterations is 15 times. Run the simulation platform to get the simulation results shown in Figures 5 and 6.

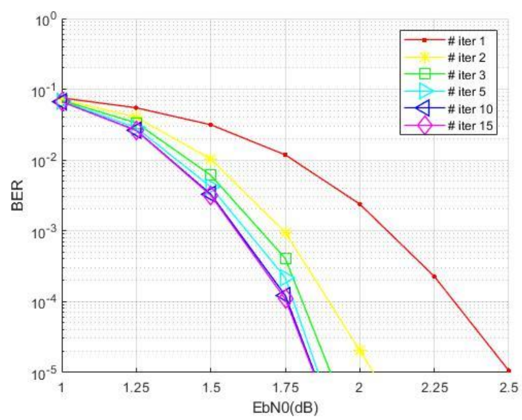

Fig. 5. LMMSE algorithm simulation results

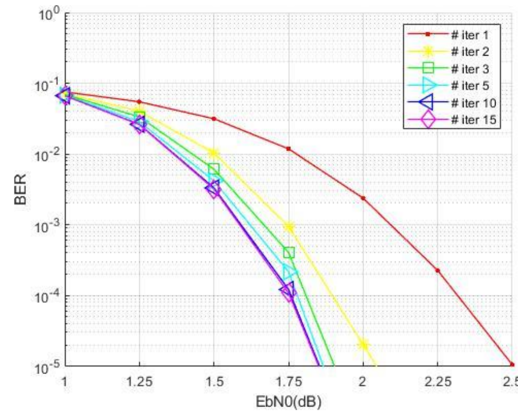

Fig. 6. AMP-G algorithm simulation results

As can be seen from the simulation results, in the strong multipath and Doppler frequency shift aviation channel, under the condition of low signal-to-noise ratio, both algorithms can significantly reduce the bit error rate and improve the system reliability. As the number of iterations increases, the BER curve drops dramatically, but the downward trend gradually converges. The curves of the 10th and 15th iterations basically coincide. The BER obtained by the iteration converges to the order of 10^{-5} at a signal-to-noise ratio of 2.5 dB, and 0.6 dB is obtained by iteration gain. So the performance is very significant.

Compare the simulation results of the two algorithms at the 1st, 2nd, 5th, and 15th iterations, as shown in Figure 7.

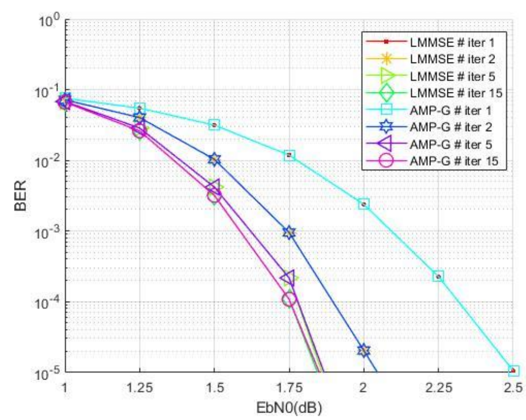

Fig. 7. Comparison of simulation results of two algorithms

By analyzing Figure 7, the BER curve drops to 0 after 2.5 dB, indicating that the algorithm can cope with channel fading caused by multipath delay and Doppler frequency shift, and has excellent performance. However, it should be noted that the simulation is based on the assumption that the channel within each OFDM symbol remains unchanged. In a real aviation channel, the channel change may be faster, and the channel conditions are worse. The algorithm results will have some impact, but the overall performance and trend are consistent.

The curves of the two algorithms are close to coinciding, and the performance is similar. Compared with traditional equalization algorithms, the LMMSE algorithm and AMP-G algorithm have greatly improved in complexity. The complexity of the LMMSE algorithm is $\mathcal{O}\left(M^3\right)$, where M is the number of receiving antennas. And the complexity of the AMP-G algorithm is $\mathcal{O}\left((28|\mathcal{A}|+33)TMNK+(2|\mathcal{A}|+3Q|\mathcal{A}|+Q)TNK\right)$, where $\mathcal{A}$ represents the modulation order, Q represents the number of mapped bits, N represents the number of transmitting antennas. Reducing the complexity of the algorithm can reduce the number of calculations per iteration. On the one hand, it can lower the processing delay at the receiving end. On the other hand, it can save the power consumption of the receiver. Considering the power limitation of the airborne receiver, in order to maintain the regular communication between the aircraft and the tower, the flight radius of the aircraft is limited, and it is possible to obtain a larger flight radius by applying iterative receiving algorithms with low complexity to an airborne receiver. In [10], the AMP-G algorithm's performance is superior to the LMMSE algorithm in high-dimensional MIMO scenarios. The reason is that the interference between high-dimensional antennas is complicated. The AMP-G algorithm approximates the expression in the process of updating the message through the factor graph. Therefore, it has distinct advantages in terms of complexity. In aviation communication scenarios, there are few antennas. The Los path amplitude coefficient is prominent, the flying height is high, and the reflection path delay is small, so the performance of the two algorithms is similar.

In-depth analysis of the iterative receiving algorithm's mechanism, the key to reducing the bit error rate lies in the information exchange during each iteration. The traditional equalizer only considers one-time compensation for channel fading, while for the soft input and soft output joint equalization and decoding system, the equalizer uses the latest output of the decoder through iterations, and the decoder uses the prior information of the latest output of the equalizer. It is thus obtaining the best decoding performance that tends to converge. From the perspective of the factor graph, during the first iteration, the information is initialized according to a uniform distribution, and the rest of the information received by the equalizer for each iteration is from the latest output of the decoding link. Different methods of scheduling calculation information lead to different algorithm performance. The approximate calculation in the scheduling process will reduce the complexity and increase the bit error rate simultaneously. We should analyze the characteristics of different systems and the range of bit error rates to compromise between the two factors.

We use an iterative receiver algorithm for airborne receivers in ground-to-air communication scenarios. In civil aviation communications, the lower bit error rate ensures the reliability of communication, allowing the aircraft to receive tower commands accurately to ensure flight safety. Passengers can also experience low-latency, highly reliable communication services and therefore get better user experience. The OFDM system ensures channel capacity and spectrum utilization, and airlines can also increase the number of flights and business volume. In terms of military aviation communications, from the perspective of modeling and simulation of multipath, noise, and Doppler frequency shift, although there are no simulation results in the military scene in this paper, the algorithm exhibits resistance to large noise, multipath, and Doppler frequency shift. Performance is an inherent advantage of the algorithm. The use of lower complexity algorithms can also reduce receiver power consumption and increase the combat radius. The tower can be better concealed and difficult to be discovered. Therefore, iterative receiving algorithm applied to military aircraft such as fighter planes and reconnaissance aircraft is also of great significance and broad prospects.

V. Conclusion

In order to improve channel capacity and spectrum utilization, the next-generation aviation communication system considers adopting the LDACS1 system that introduces OFDM technology in ground-to-air communication scenarios. But at the same time, the aviation channel has the characteristics of strong multipath, large frequency shift, and susceptibility to weather, which will cause severe channel fading. The performance of the traditional equalization algorithm is not ideal, and the complexity is high, resulting in high receiver power consumption and considerable transmission delay. Based on safety, system performance, user experience and other factors, this paper proposes to use iterative receiving algorithm of information, namely LMMSE algorithm and AMP-G algorithm. Both algorithms can effectively cope with the time-varying, multi-path fading and Doppler frequency shift of the aviation channel, improve the reliability of communication and user experience, save receiver power, and increase the flight radius. At the same time, the design process of the AMP-G algorithm inspired us to use the factor graph to adaptively design a low complexity receiving algorithm that meets the error performance in different communication environments.

VI. Acknowledgement

This work was supported by the Basic scientific research project of Beijing University of Posts and Telecommunications (No. 2019RC02).

References

[1] Liu Xiaofeng, Sun Shaohui, Du Zhongda, et al. 5G wireless system design and international standards [M]. Beijing: People's Posts and Telecommunications Press, 2019: 4-5.

[2] Zhou Peng. Research on the implementation of key technologies for OFDM transmission and reception for aeronautical channels[D]. University of Electronic Science and Technology, 2015.

[3] Li Mengru. Research on OFDM time-frequency synchronization algorithm for L-DACS1 system[D]. Chongqing University, 2016.

[4] Yu Lianjiang. Equalization technology and FPGA implementation of high-speed wireless channel transmission[D]. Nanjing University of Aeronautics and Astronautics, 2012.

[5] Qin Lijun. Research on Channel Estimation and Equalization Technology in Single Carrier Aviation Communication System[D]. Nanjing University of Aeronautics and Astronautics, 2012.

[6] Henk Wymeersch. Iterative receiver design [M]. United Kingdom: Cambridge University Press, 2007: 19-76, 187-225.

[7] Guo Q, Huang D D. A concise representation for the Soft-in Soft-out LMMSE detector[J]. IEEE Communications Letters, 2011, 15(5):566-568.

[8] Guo Q, Huang D, Nordholm S, et al. Iterative frequency domain equalization with generalized Approximate Message Passing[J]. Signal Processing Letters IEEE, 2013, 20(6):559-562.

[9] Wu S, Kuang L, Ni Z, et al. Low-Complexity Iterative detection for large-scale multiuser MIMO-OFDM systems using Approximate Message Passing[J]. Selected Topics in Signal Processing, IEEE Journal of, 2014, 8(5):902-915.

[10] Wu S, et al. Message-Passing receiver for joint channel estimation and decoding in 3D massive MIMO-OFDM systems[J]. IEEE Transactions on Wireless Communications, 2015, 15(12):8122-8138.

[11] Zhao Youyou. Research on channel estimation algorithm based on prior information in aviation communication system [D]. Zhengzhou: Zhengzhou University, 2019.

[12] David Tse. Fundamentals of wireless communication [M]. Li Qiang, Zhou Jin, et al. translated. Beijing: People's Posts and Telecommunications Press, 2007: 10-35.