Performance Analysis of UAV Uplink Communication Technology

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Abstract. In order to meet the reliability and anti-jamming requirements of UAV communication system, the anti-jamming performance of the up-link communication technology is analyzed by comparing the influence of different jamming on the signal and the influence of Rice channel on the signal on the basis of in-depth study of the communication mechanism of the low-altitude UAV communication link. The simulation results show that the anti-jamming performance of the signal is better when the interference is added in the upstream communication technology, and the anti-broadband interference of the signal is better than other interference types when the channel is added.

1. Introduction

With the continuous progress of science and technology, UAV plays a key role in modern battlefield. The communication link system of UAV is undoubtedly the most important part of UAV[1]. UAV upstream link is to transmit and receive remote control commands from ground station to UAV, and to tract UAV to fly according to remote control commands from ground control station, and to control airborne equipment. Downlink is to complete remote sensing data from UAV to ground control terminal, mainly the current attitude, position of UAV, status and sensing information of airborne equipment[2].

For UAV link communication channel, whether between UAV or between UAV and ground station, UAV receiver receives not only the refraction component signal, but also the reflection refraction and atmospheric diffraction component of various signals. In document [3], different ground conditions correspond to different characteristics of reflected waves; in document [4], it is further shown that different surface environments have different fading conditions. Therefore, for the data link communication channel, the Rice channel fading channel in different flight states can be selected when modeling.

2. Mechanism of DSSS Communication System

Direct Sequence Spread Spectrum (DSSS) technology is widely used in UAV upstream links because of its low detection rate and anti-jamming[5]. DSSS modulates the low bit rate signal with the high bit rate PN code sequence. The transmitter principle of direct spread spectrum technology is shown in Fig.1. At the transmitter, the data source converts 1 0 1 0 symbols into 1 -1 1 -1 information codes
with bipolarity by encoder, spreads the information codes with a group of pseudo-random sequences generated randomly by the pseudo-random code generator, and finally multiplies and modulates the carrier signals of a specific frequency by the carrier generator, and transmits the generated signals through the transmitter.

Fig.1 Principle block diagram of signal transmitter

Fig.2 is the schematic block diagram of the signal receiving terminal. At the receiving end, the signal is received by the receiver, filtered by the filter and demodulated by the local modulator, which generates the same carrier frequency as the center frequency of the transmitter, and the same pseudo-code sequence is also generated for despreading. Finally, the source signal is decomposed.

Fig.2 Principle block diagram of signal receiving terminal

3. Rice Channel
The transmitted signal decays through the Rice channel and obeys the Rice distribution. Suppose that the complex envelope of the signal propagating in Rice channel is as follows:

$$s'(t) = \text{Re}[s(t)e^{j2\pi f_{1}t}]$$

(1)

\(S(t)\) is a signal for ground station, \(f_{c}\) is the carrier frequency of the transmitted signal[6]. If the position of the transmitter of the ground station is relative to that of the receiver of the UAV, the received signal at the receiving end can be expressed as:

$$y(t) = \lim_{N \to \infty} \sum_{n=1}^{N} a_{n} e^{j2\pi f_{n}t} e^{j2\pi f_{1}t} e^{j\theta_{n}} s\left(t - \frac{d_{n}}{c} + \frac{\Delta d_{n}}{c}\right)$$

(2)

\(f_{n}\) represents the frequency shift of the nth scattering component of the received signal of the UAV. \(\Delta d_{n} = vt \cos \theta_{n}\) is the path change length in time, because \(\Delta d_{n} / c\) is much smaller than \(d_{n} / c\). The received signal may be expressed as:

$$y(t) = \lim_{N \to \infty} \sum_{n=1}^{N} a_{n} e^{j2\pi f_{n}t} e^{j\theta_{n}} s\left(t - \tau_{n}\right)$$

(3)

For the Rice channel, the paths of the multipath effect produced by each signal arriving at the UAV receiver are inseparable, and with \(\tau_{n} = 0 \forall n\), the above formula can be expressed as follows:

$$y(t) = s(t) \lim_{N \to \infty} \sum_{n=1}^{N} a_{n} e^{j2\pi f_{n}t} e^{j\theta_{n}}$$

(4)

At this time, the impulse response of the channel can be expressed as:
\[ h(t) = \lim_{N \to \infty} \sum_{n=1}^{N} a_n e^{j2\pi f_n t} e^{j\theta_n} \]  \hspace{1cm} (5)

Fourier transform of impulse response \( h(t) \) with respect to delay \( \tau \) can obtain the transmission function of the channel:

\[ H(f,t) = \lim_{N \to \infty} \sum_{n=1}^{N} a_n e^{j2\pi f_n t} e^{j\theta_n} \]  \hspace{1cm} (6)

It can be seen that the transmission function is independent of the frequency \( f \) because the channel impulse response is independent of the delay \( \tau \), and the attenuation of all bands is the same. \( a_n \) has the greatest influence on the function. Because \( a_n \) is the amplitude coefficient of the scattering path, not a fixed value, it can be changed by the Rice factor \( K \). Rice factor \( K \) can be expressed as:

\[ K_{rice} = \frac{\tilde{a}^2}{c^2} \]  \hspace{1cm} (7)

In the formula, Rice factor \( K \) can also be said to be the power ratio of the direct component and the scattering component, where \( c^2 \in \mathbb{R} \) is the variance of the scattering process of the zero-mean orthogonal component of the desired signal.

4. Simulation Process and Analysis

The simulation parameters of DSSS signal are: carrier amplitude 1 V, pseudo code rate 40.96 Mbps, carrier frequency 80 MHz, sampling frequency 10 MHz, symbol number 160, simulation time 0.05 s, initial phase 0.

In this paper, the Anti-jamming Analysis of DSSS signal is carried out by adding Rice channel and jamming signal. When the Rice factor \( K \) equals 10dB, the channel noise is set, and three kinds of interference signals are set, including full-band interference, partial-band interference and multi-band interference. Fig.3 and Fig.4 are power spectrograms of signals without interference and channel, which are convenient for comparison and analysis when interference is added below.

4.1. Performance analysis of full-band interference

Full-band interference is to add the white Gaussian noise after band-pass filtering to the spread spectrum signal, so that the noise of the signal is relatively high, so as to achieve the purpose of anti-interference of the measured signal[8].

The time domain expression of full-band interference signal is:

\[ J(t) = \int_{-\infty}^{\infty} j(\tau) * b(t-\tau) d\tau \]  \hspace{1cm} (8)

Formula:
The power spectrum images of DSSS signal and interference signal are obtained by simulation as shown in Fig.5 and Fig.6. As can be seen from Fig.5, the central frequency is 10M and the bandwidth is 2M. Fig.6 is a signal superimposed by the interference signal and the original signal. The power spectrum image of the original signal in Fig.4 is covered by the interference signal in Fig.5. From Fig.6, it can be seen that the power spectrum of the original arc has become a power spectrum image of broadband interference.

$$b(jw) = \begin{cases} 1 & |w - 1050| \leq 150 \\ 0 & \text{others} \end{cases} \quad (9)$$

Fig.7 and Fig.8 show the BER curves of signals with full-band interference. The figure shows that the bit error rate increases with the increase of the signal to signal ratio. When the dry-to-signal ratio is 0 dB, the BER of DSSS signal decreases to 0; when the dry-to-signal ratio is 19 dB, the BER of the system is 0.38. Fig.7 shows the BER curve of a signal with or without channel interference. Compared with Fig.8, although there is no effect on the signal when only channel interference is present, the bit error rate of the superposition of channel and interference signal increases after adding interference.

4.2. Performance analysis of partial band interference

Partial band interference is to interfere with spread spectrum signals in some communication bands. Part-band interference is similar to full-band interference, but part-band interference is half or a quarter of full-band interference. The power spectrum image of DSSS signal and the power spectrum image of partial band white Gaussian noise interference signal are shown in Fig.9 and Fig.10. As can be seen from Fig.9, it is a partial band interference with a center frequency of 10M and a bandwidth of
0.5M. Fig.10 is a signal superimposed on the original signal. The power spectrum of the original signal in Fig.4 above is partially wrapped by the interference signal in Fig.9. From Fig.10, it can be seen that the power spectrum of the original arc has been partially transformed into the power spectrum of the partial interference, while the signal without interference is still the power spectrum of the signal.

![Fig.9 Partial band interference power Spectrum](image1)

![Fig.10 Adding partial interference signal power Spectrum](image2)

Fig.11 and Fig.12 show the BER curves of the signal with partial band interference. The figure shows that the bit error rate increases with the increase of the signal to signal ratio. The error rate is 0 when the dry-to-signal ratio is 0 dB and 0.44 when the dry-to-signal ratio is 19 dB. Fig.11 is the BER curve of the signal with or without channel interference. Compared with Fig.12, although it has no effect on the signal with only Rice channel interference, the BER of the superposition of channel and interference signal is higher than that of the simple addition of interference.

![Fig.11 BER curve of signal under partial frequency band interference](image3)

![Fig.12 BER comparison curve with or without Rice channel](image4)

4.3. Performance analysis of multifrequency jamming

Multifrequency interference, commonly known as comb spectrum interference, is the interference of multiple frequencies on the originally transmitted signal. The time domain expression of multi-frequency interference signal can be expressed as:

\[
J(t) = P_1 \cdot \sin(2\pi f_1 t + \varphi_1) + P_2 \cdot \sin(2\pi f_2 t + \varphi_2) + \cdots + P_n \cdot \sin(2\pi f_n t + \varphi_n) \quad (10)
\]

In the formula, \(P_1, P_2, \ldots, P_n\) is the power of the multi-frequency interference signal, \(\varphi_1, \varphi_2, \ldots, \varphi_n\) is the initial phase of the multi-frequency interference signal, \(f_1, f_2, \ldots, f_n\) is the carrier frequency of the
multi-frequency interference signal. In general, \( f_1, f_2, \ldots, f_n \) is determined by the frequency band range of the interfered signal detected by its own side[9].

In this paper, the frequency of multi-frequency interference signal is set to 5, and the carrier frequencies are 9.2 MHz, 9.6 MHz, 10 MHz, 10.4 MHz and 10.8 MHz, respectively. The power spectral density of spread spectrum signal and multi-frequency interference signal are shown in Fig.13 and Fig.14. From Fig.13, we can see that the center frequency is the same as the set frequency. Fig.14 is a signal superimposed on the original signal. The power spectrum of the original signal in Fig.4 above is partially covered by the interference signal in Fig.13. From Fig.14, it can be seen that the power spectrum of the original arc has been partially transformed into the power spectrum of the multi-frequency interference, while the undisturbed signal is still the power spectrum of the signal.

![Fig.13 Multifrequency interference power spectrum](image1)

![Fig.14 Signal power spectrum with multifrequency interference](image2)

Fig.15 and Fig.16 show the BER curves of signals with multi-frequency interference. The figure shows that the bit error rate increases with the increase of the signal to signal ratio. The error rate is 0 when the dry-to-signal ratio is 0 dB and 0.39 when the dry-to-signal ratio is 19 dB. Fig.15 is the BER curve of the signal with or without channel interference. Compared with Fig.16, although it has no effect on the signal with only Rice channel interference, the BER of the superposition of channel and interference signal is higher than that of the simple addition of interference.

![Fig.15 BER curve of signal under multifrequency interference](image3)

![Fig.16 BER comparison curve with or without Rice channel](image4)

5. Conclusion
UAV upstream link communication technology and Rice channel are studied, and the anti-jamming performance of the signal is modeled, simulated and analyzed. The bit error performance of the signal under full-band interference, partial-band interference and multi-band interference is analyzed
emphatically. At the same time, the BER curves of different ICR are established by comparing Rice channels under different interference conditions, and the comparison and analysis are carried out. The simulation results show that the anti-jamming performance of the signal is good by comparing the BER curves of the three kinds of jamming after adding the jamming to the signal. When adding the Rice channel, the BER of the original jamming signal obviously increases. Compared with the three kinds of jamming, the display signal in the graph is better than other jamming after passing through the Rice channel.

Acknowledgments
This work is supported by the National Defense Basic Scientific Research Planed Project (2018) Natural Science Fund of Liaoning Province NO.20170540775, Program for Liaoning Innovative Research Team in University, Science and Technology Foundation from Liaoning Education Department No.L2015462, Shenyang Ligong University Liaoning Province Information Network and Countermeasure Technology Key Laboratory Open Foundation (2015).

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