Design and Simulation of a Weak Signal Detection Algorithm: Multiple Signal Sending Algorithm

Zilong Wang 18281218
wangzilong@bjtu.edu.cn

***Abstract*—The communication between the earth and the moon is obscured by the noise. Since the noise that produced by the long-distance interference is inevitable, an algorithm for the weak signal detection, which is called the multiple signal sending algorithm, is designed for the purpose of solving this de-noise problem in the following content. The key of the multiple signal sending algorithm is to send and receive one signal for many times, and consequently the accuracy of received signals can be improved significantly. The results of simulation that shown below proved the validity of the multiple signal sending algorithm.**

***Index Terms*—weak signal detection system, de-noise problem, earth-moon communication, simulation**

I. Introduction

The technology of weak signal detection is widely used in radar, communication, sonar, earthquake and industrial measurement [1].

In free space, if a spherical wave is radiated at the transmitting point, the power at the receiving point would be $P_r = \frac{P_t}{d^2}$, where P_r is the power at the receiving point, P_r is the power at the transmitting point and d is the distance between the two points. Considering the distance between the moon and the earth is $384,400$km, the power at the receiving point is extremely weak. Compared with noises, the amplitude of the useful signal is weak and completely obscured by the noise [2].

At present, a weak signal detection algorithm is important in the communication between earth and moon. In this paper, we will focus on the multiple signal sending algorithm and its simulation.

II. Related Work

A. ALE-FFT Algorithms [3]

The FFT acquisition is a normal method in this case and ALE-FFT algorithm, which ALE is added before FFT, can enhance the ability of weak signal detection, especially for the weak signal which has big dynamic range of Doppler frequency. In residual carrier acquisition mode, the ALE is equivalent to an adaptive band-pass filter which enhances the acquisition signal noise ratio(SNR) greatly.

B. Wavelet Transform [4]

The basic meaning of Wavelet Transform(WT) is the x signal through the scale and shift, decomposing to a series of sub-frequency with the different spatial resolution, the different frequency characteristics and the directional characteristic innertube signal, this innertube signal has a good time domain, a frequency band and other partial characteristics. Therefore the wavelet analysis to signal has an excellent detection performance under low SNR.

III. The Proposed Method

A. Problem Description

Given the signal $x(n)$ sent from moon where $x(n) = \pm 1$ with equal probability. $\omega(n)$ is white gaussian noise and $\omega(n)$ obeys $N(0,1)$. Suppose $y(n)$ is the signal received on earth, we have:

$$y(n) = hx(n) + \omega(n)$$

where h is the weaken ratio of the signal traveling from moon to earth. In this problem, $h = 10^{-3}$. The problem is to recover $x(n)$ from $y(n)$.

B. Multiple Signal Sending Algorithm

The $\omega(n)$ is always an independent variable obeys $N(0,1)$. If we send each signal for N times, The sum of $\omega(n)$ would be much smaller than the sum of $hx(n)$ for N times due to Central Limit Theorem [5]. Taking $n = 1$ as an example:

$$y(n) = h\,x(1) + \omega(n) \tag{1}$$

We calculate the sum of $y(n)$ and **OP(1)** can be developed as follows **OP(2)**:

$$\sum_1^N y(n) = Nhx(1) + \sum_1^N \omega(n) \tag{2}$$

When N is large enough, we can recover x(n) from y(n) by the sign of $\sum_1^N y(n)$. If $\sum_1^N y(n) \geq 0$, we can interpret $x(n)$ from $y(n)$ as 1. In contrast, if $\sum_1^N y(n) < 0$, we can interpret $x(n)$ from $y(n)$ as -1.

IV. Simulation

In this section, we study the effect of Multiple Signal Sending Algorithm by analyzing the *Bit Error Ratio* (BER) versus N by the simulation.

We employ a signal array $\mathbf{X} = [x_1, x_2, ..., x_{10^3}]$ where $\mathbf{x}_i = \pm 1$ with equal probability. A noise array $\mathbf{W} = [\omega_1, \omega_2, ..., \omega_{10^3}]$ is used, where ω_i is N sum of single gaussian noise obeying $N(0,1)$. Then we can get the input signal array $\mathbf{Y} = [y_1, y_2, ..., y_{10^3}]$ by the following equation:

$$\mathbf{Y} = Nh\mathbf{X} + \mathbf{W}$$

If y_i is positive, then we assume y_i is 1. Otherwise y_i is -1. Comparing x_i and y_i respectively and calculating the BER.

We simulate different N and the figure of BER versus N as follows Fig. 1.

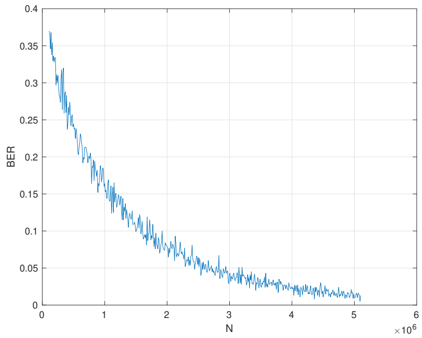


Fig. 1. BER vs. N

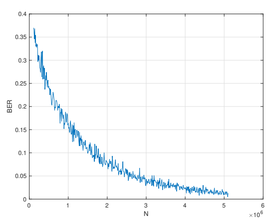
A. Comparing of different h

From **OP(2)** we find:

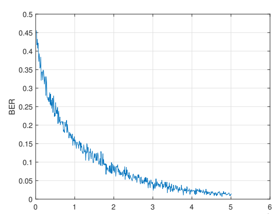
$$\begin{cases} Nhx \ \propto \ k_1 N \\ \sum_1^N \omega(n) \ \propto \ k_2\sqrt{N} \end{cases}$$

where k_1 and k_2 are constant. So if h is reduced by 10 times, then N should be expanded by 100 times.

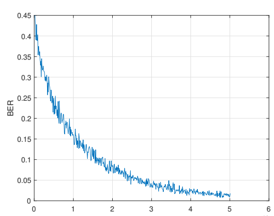
Here is the simulation with different h:



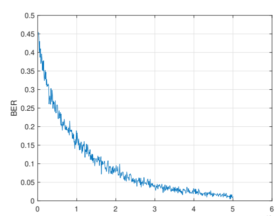
$h = 10^{-3}$



$h = 10^{-4}$



$h = 10^{-5}$



$h = 10^{-6}$

BER vs. N with different h

V. Result

BER decreases while N grows. When the magnitude of N reaches 10^6, BER is over 15%. As shown in Fig.1, BER is inversely proportional to N. If we want to obtain lower BER, we can only sacrifice transmission efficiency.

Due to the fact that BER is inversely proportional to N, it is hard to decrease when the BER is below 10%. If we want to get an accurate signal, N should be greater than 1.6×10^6 (BER is lower than 10%). However, if we need the BER below 1%, time consumption will increase geometrically.

When h is different, we realize that N is squared growing. If $h = 10^{-6}$, N should be more than 10^{12}. It means that one bit information should be sent for 10^{12} times. Considering the communication frequency between the moon and the earth is about 40GHz [6], one bit information should be sent for 250sec. The bandwidth is only 0.004bps when $h = 10^{-6}$. Here is the bandwidth when h is different.

h	10^{-3}	10^{-4}	10^{-5}	10^{-6}
Bandwidth	4Kbps	40bps	0.4bps	0.004bps

From the table we know that if we have to use Multiple Signal Sending Algorithm, the h should be greater than 10^{-3} in order to ensure the bandwidth of the communication.

VI. Conclusion

In this paper, multiple signal sending algorithm is proposed and simulation is discussed. The multiple signal sending algorithm can acquire weak signal accurately in the problem of the earth and the moon communication. From the simulation of the algorithm, we get that the value of N should be between 1.6×10^6 to 6×10^6 when $h = 10^{-3}$, so that it can achieve both efficiency and accuracy.

The algorithm studied in this paper will be particularly useful when the signal between the earth and the moon is very weak and where white gaussian noise is the predominant noise source.

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