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A best method of demodulation algorithm for UNFSK applied in transportation

Yanfang Shou [a], Jianmin Xu [a], Xiaotao Deng [a,b,*]

[a] *Department of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510640, China*
[b] *Electronic Engineering Institute of Naval Engineering University, Wuhan 430033, China*

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ABSTRACT

The frequency shift of the ultra-narrow frequency shift keying (UNFSK) is far less than the ordinary binary frequency shift keying (FSK) method. Because the two frequencies of UNFSK are extremely close, the traditional demodulation method cannot separate them successfully. This study aims to successfully demodulate the UNFSK signals by applying cycle extension and notch filter. The signal processing procedure is as follows: First, the sampling signals have been made cycle extension to enlarge their spectrum difference between signal 0 and 1; secondly, the cycle extension signals have been processed by the notch filter algorithm and finally, we could get the information by sentencing the filtering result. Finally, the method is applied in transportation. The simulation results proved that the algorithm greatly enhanced UNFSK signal demodulation performance, compared to the traditional demodulation method. There can be 2–3 dB improvement in performance, which is very suitable for UNFSK.

1. Introduction

Frequency shift keying (FSK) is one of the most traditional methods of signal modulation by changing the signal frequency to transmit the information. Binary frequency shift keying (BFSK) has two different frequencies which are used to indicate the information 0 and information 1. There are some difference between these two frequency points; the greater the value, the easier information can be demodulated out of the original signal. For wireless communications, channel resources are very valuable, and there are great restrictions on the useful bandwidths. If we use the current BPSK technology to transmit high-speed data, it is necessary to make great frequency difference to ensure the successful demodulation in the receiving terminator which will lead to the large bandwidth occupied by BFSK modulation, so that an irreconcilable contradiction occurs between the information rate and a signal bandwidth. Therefore, when the channel bandwidth resources are very limited in order to increase the data transmission rate, it is necessary to adopt various methods to obtain the highest bandwidth efficiency, which is the information transmitting rate in units of frequency bands (in bit/s/Hz).

In recent years, Walker (2003, 2004) proposed an UNB method to increase spectrum efficiency; Wu (2004, 2007) and Yang, Hao, Zhou, and Zhou (2007) have expressed their support from the theoretical and practical applications, respectively. However, Li and Yao (2003) have put their questions to opposite this method. The key question focuses on whether there is information available in the sideband. In the following years, Walker (2007), Feng and Wu (2007) and Deng, Gao, and Lin (2007) give the explanation from the Shannon theory and the analysis of band-depth study. So far, the ultra-narrow-band theory has not been determined. However, from the current information on all aspects, the ultra-narrow-band modulation methods certainly have an obvious high bandwidth efficiency, but the literature about the ultra-narrow-band signal demodulation algorithm is few. Including the HR Walker himself, nobody put a practical demodulation method for this UNB modulation. But no matter whether the UNB modulation can be used, it put forward a new direction of development for communications workers. Based on the traditional way of frequency shift keying modulation, jumping out of the HR Walker's thinking, this article designs a practical modulation and demodulation technology a practical modulation and demodulation technology in transportation wireless communication domain which presents high-frequency spectrum utilization named ultra-narrow-FSK modulation and demodulation techniques (UNFSK), and solves the problem on transportation management in urgent events and vehicles monitoring management excellently.

2. Limitations of the traditional BFSK demodulation technology

Binary frequency shift keying is a very simple method of signal modulation, which uses the different frequencies to indicate the required message. Its time-domain signal expressions are as follows:

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* Corresponding author at: Electronic Engineering Institute of Naval Engineering University, Wuhan, Hubei 430033, China. Tel.: +86 010 66969366, 13751865601 (mobile).

E-mail addresses: Yanfangshou@163.com (Y. Shou), XiaotaoDeng@tom.com (X. Deng).

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$$S_{2\mathrm{FSK}}(t) = \left[\sum_n a_n g(t - nT_s)\right]\cos\omega_1 t + \left[\sum_n \overline{a_n} g(t - nT_s)\right]\cos\omega_2 t \tag{1}$$

where $\omega_1 = 2\pi f_1$, $\omega_2 = 2\pi f_2$, $\overline{a_n}$ is the anti-code of a_n,

$$a_n = \begin{cases} 0, & \text{probability is } P \\ 1, & \text{probability is } 1 - P \end{cases} \qquad \overline{a_n} = \begin{cases} 1, & \text{probability is } P \\ 0, & \text{probability is } 1 - P \end{cases} \tag{2}$$

For those similar modulation methods with UNFSK, Li and Wu (2003) and Saywood and Wu (2001) have already demonstrated their modulation characteristics of a very narrow bandwidth. However, the success of such methods depends on the demodulation process rather than on the modulation process. This is because for the binary FSK signal, the traditional methods are non-coherent demodulation detection and coherent detection. In addition, there are other methods on the BFSK demodulation, such as the frequency method, zero-crossing detection and differential detector law. All of the above demodulation methods are limited by the difference of the two frequencies which must have a certain margin. When the interval of frequency shift is too small, that is to say two signal frequencies are very close, the signal will seriously overlap in the frequency domain, with the result that the traditional methods cannot successfully demodulate the signal from the demodulator to the original information. So we cannot improve the binary frequency shift keying modulation frequency spectrum utilization by reducing the difference between the two signal frequencies.

3. The best demodulation algorithm for UNFSK

UNFSK modulation and FSK modulation are very similar to each other because they both use the information bits to modulate the signals' main frequencies. The only difference is that the UNFSK can use two very similar frequencies to transmit 0 and 1 information. As shown in Fig. 1, the following chart has selected two very similar frequencies to transmit the signal 0 and 1, where the frequencies of signal 0 and 1 are $f_1 = 50$ Hz and $f_2 = 50.793$ Hz and their frequency interval is 0.793 Hz. In this case, we use the traditional non-coherent detection and coherent detection method to simulate the signal demodulation, but the result is very bad. Even when the SNR is set to 20 dB, the BER is still at 10^{-2} level which is almost a failure of demodulator. Therefore, in order to successfully demodulate the information from a very narrow-band signal, we must adopt a special way to deal with.

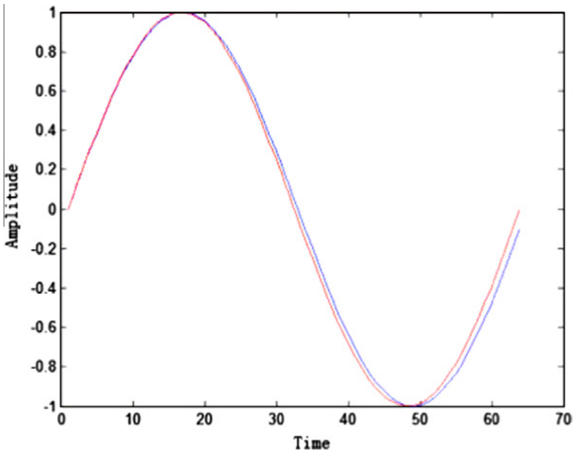

Fig. 1. Two extremely similar signal waveform.

3.1. Cycle extension method

The purpose of the signal cycle extension is to separate the two signals as far as possible by increasing the difference between the two similar frequencies.

Here, we analysis one cycle symbol on the waveform for the UNFSK modulation mentioned above, which is given in Figs. 2a and 2b. First, we sample the waveform in one signal cycle; the sampling frequency is much higher than the signal frequency of 0 and 1, which is the basis for the demodulation. Assuming the value sequences after sampling is as follows:

$$\{s_1(1), s_1(2), \ldots, s_1(N)\} \quad \{s_2(1), s_2(2), \ldots, s_2(N)\} \tag{3}$$

When these two frequencies are very close to each other, after making the Fourier transform on these two information sequences, we will find that they are serious overlap on the spectrum.

However, if the two signals are separately making cycle extension, we can find the spectrum analysis will be another result. Here, we have made the two signals, an extension of the 100 cycle times. The waveform and spectral analysis results are as follows.

We can understand from the above results that the two signals have been significantly more effectively separated on the spectrum after extension of the signal waveform. The result also has been supported in theory. Assuming the time-domain signal waveforms in a frequency cycle $[0, T]$, take any signal as an example, which are as follows:

$$s(t) = A\cos(2\pi f t + \phi) + n(t) \tag{4}$$

where $n(t)$ is the noise signal, $T = 1/f$. When the signal uses the time T for the extension cycle, there is no doubt that the first useful part of the signal will converge at the fastest speed. In the limit case, it will converge to one line. At the same time, noise signal will also converge, but the convergence rate is far less than the useful signal. Thus, after cycle extension process, we have enlarged the difference between the signal and noise which is the foundation to successfully demodulate the useful information.

3.2. Notch filtering algorithm

Notch filter is to compare the received signal waveform to determine whether frequency waveform is 0 or 1 and then to determine the message. First of all, it is necessary to design the filter according to the UNFSK frequency. Since the two frequencies have very small intervals, so notch filter will be designed. Notch filter is a very narrow band-stop filter. Based on the analog prototype filters, we can get a digital notch filter after a certain transformation. There are usually two ways to design the notch filter.

One way is to use analog frequency domain band-stop transformation method first and then use digital method to design digital band-stop filter.

Another way is directly transforming the analog low-pass prototype filter into a digital band-stop filter z-plane through the s-plane.

Here, the second method has been chosen.

Transformation relations between the analog low-pass and band-stop are as follows:

$$s = \frac{\overline{\omega}_0^2 p}{p^2 + \overline{\omega}_0^2} \tag{5}$$

where s is analog low-pass prototype Laplace variable ($s = \sigma + j\omega$), p is analog band-stop prototype Laplace variable $(p = \overline{\sigma} = j\overline{\omega})$, $\overline{\omega_0}$ is the geometric center frequency of the analog band-stop filter.

Through the bilinear transform,

$$p = 2fs\frac{z - 1}{z + 1} \tag{6}$$