Spectrum Sensing Technology in the Space Network

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Abstract

With the development of radio services, available spectrum resources become more and more nervous. As the current wireless network usually adopts the static spectrum allocation policy, spectrum scarcity of space is an illusion. Spectrum sensing technology can detect primary user in the time domain, frequency domain and space domain, whereby the spectrum usage. Over dynamically detecting and using idle spectrum, the utilization of the spectrum can be greatly improved. The inter-satellite links signal transmission usually adopted spread spectrum signal mode. When the primary user signal is spread spectrum signal, it is difficult to perceive the presence of primary users by available Spectrum sensing technology. In this paper, establish the GPS navigation satellite signal based on Matlab and STK software, using wavelet transform (WT) spectrum to detect the GPS signal, getting the final conclusion.

1. Introduction

Currently, space wireless network adopts the static spectrum allocation policy, which dividing available spectrum into many continuous, non-overlapping spectrum segments for different users. The user with exclusive spectrum is called an authorized user or primary user. With the development of radio services, the number of primary user gradually increasing, the shortage of available space spectrum is increasing serious. According to the survey report of FFC in 2002 [1], the actual authorized spectrum segment is not be fully utilized in time and space. A detection of spectrum once in New York, the largest utilization in the 30MHz ~ 3GHz spectrum is only 13.1%, which reveals a shortage of spectrum resources is just an illusion, the free frequency band is called "spectrum hole."Cognitive radio technology could find the "spectrum hole" and authorize secondary access in it [2], without affecting normal communication. As an intelligent and adaptive spectrum sharing technology by dynamically detecting and using free spectrum segments, which greatly improve the spectrum utilization to solute the problem of spectrum resources scarcely.

2. Spectrum Sensing Method

Spectrum sensing is one of the key technologies of cognitive radio systems. Users must monitor real-time changes of the spectrum to avoid conflicting with authorized users. Accuracy and reliability of spectrum detection determines whether it will affect the normal communication of authorized users. Spectrum sensing typically use some detection algorithms to perceive the spectrum usage, which performance is usually detected by the probability of false alarm and missed. The current spectrum detection algorithm has several categories, which include Energy Detection, Cyclostationary Feature Detection [3], Discrete Wavelet Transform [4] and Higher Order Statistics Testing.

Energy detection algorithm has poor performance at low SNR, which cannot be applied to the spread spectrum signal, direct-sequence signal and FM signals. Cyclostationary feature detection can be applied to the spread spectrum signal, but needs large amount of detection volume and long detection time. Higher-order statistics require the probability density function of noise having symmetric distribution. The discrete wavelet detection can simultaneously detect multiple channels without signal information of authorized users in short time. In Chapter 3, the wavelet transform algorithm is used for spread spectrum signal detection as spectrum sensing module.

3. Inter-satellite Link Signal

In currently, the inter-satellite link signal is usually adopt the spread spectrum signal model. Spread spectrum signal has been widely applied in communication, navigation and monitoring, because it has great invisibility and interference immunity, where information is widened to a much wider frequency band. When the primary user's signal

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is spread-spectrum model having widener bandwidth than data, the power spectral density is small and distribution over a wide frequency band, the spectrum sensing is difficult to perceive the primary user. In this paper, we use Matlab to establish GPS-L1 signal as the primary user signal and identify it by the wavelet transform algorithm.

3.1 C/A Code

The C/A code of GPS is a 1023 bit deterministic sequence called PN or PRN code, when transmitted at 1.023 megabits per second, repeats every millisecond. These sequences only match up, or strongly correlate, when they are exactly aligned. Each satellite transmits a unique PRN code, which does not correlate well with any other satellite's PRN code [6, 7].

$$\begin{aligned} G_1 &= 1 + t^3 + t^{10} \\ G_2 &= 1 + t^2 + t^3 + t^6 + t^8 + t^9 + t^{10} \end{aligned} \tag{1}$$

3.2 Navigation message

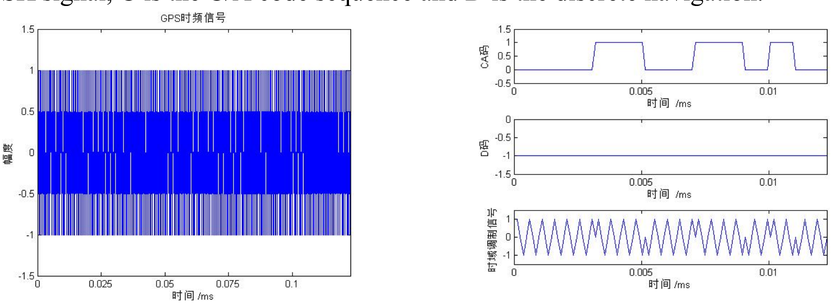
The navigation message itself is constructed from a 1,500 bit frame, which is divided into five subframes of 300 bits each and transmitted at 50 bit/s [6, 7]. Each subframe, therefore, requires 6 seconds to transmit. Each subframe has the GPS time. Subframe 1 contains the GPS date (week number) and information to correct the satellite's time to GPS time, plus satellite status and health. Subframes 2 and 3 together contain the transmitting satellite's ephemeris data. Subframes 4 and 5 contain components of the almanac.

3.3 Modulated Baseband Signal

GPS-L1 signal is a BPSK modulation signal.

$$S_{L1i} = \sqrt{2P} G_i(t) D_i(t) \cos(\omega_{L1} t + \varphi_0) \tag{2}$$

P is signal power; $G_i(t)$ is the C/A code sequences; $D_i(t)$ is navigation message, ω_{L1} is the carrier frequency (1575.42MHz); t is the GPS system time. Simulated 1ms GPS signals, each carrier has 8 sampling points, and sampling frequency is $f_s = 8 f_0 = 8 \times 1.023 = 8.184 MHz$. Every millisecond has 8184 sampling points. Carrier frequency is $f_{L1} = 1575.42 MHz$. Figure 1(a) shows the GPS time domain signal with 1000 sample points, figure 1(b) shows the structure of GPS-BPSK signal, C is the C/A code sequence and D is the discrete navigation.



(a) (b)

fig. 1 the GPS time domain signal

4. Discrete Wavelet Transform of GPS signals

4.1 Wavelet transforms modulus maxima

Assumed the receiver signal is $x(t)$:

$$x(t) = s(t) + n(t) = \tilde{s}(t) e^{j(\omega_c + \varphi_0)} + n(t) \tag{3}$$

Where $s(t) = \mathrm{Re}\left\{\tilde{s}(t) e^{j\omega_c t}\right\} = S_{L1i}(t)$ is modulate complex waveform, $n(t)$ is a complex Gaussian white noise source of power $E[|n(t)|^2] = 2\sigma_\varepsilon^2$, $\omega_c = \omega_{L1}$ is carrier frequency, and φ_0 is the carrier phase.

$$\tilde{s}(t) = D(t)e^{j\varphi_0} \tag{4}$$

The continuous wavelet transform of a signal $s(t)$ is defined as

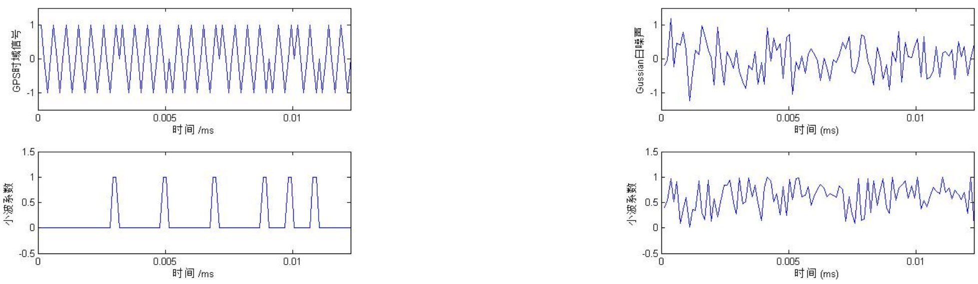
$$CWT(a,\tau) = \int s(t)\psi_a^*(t)dt = \frac{1}{\sqrt{a}} s(t)\psi^*(\frac{t-\tau}{a})dt \tag{5}$$

Where a s the scale, τ is the translation, and the superscript * denotes complex conjugate. $\psi(t)$ is the mother wavelet, and $\psi_a(t)$ is the baby wavelets coming from time-scaling and translation of $\psi(t)$.

Signal processing must be discrete in compute. Note that there is a 0.5 time shift in the discrete Haar wavelet, lining with changes of carrier. The discrete Haar wavelets are

$$\frac{1}{\sqrt{a}}\psi(\frac{k}{a}) = \begin{cases} -1/\sqrt{a} & k = -a/2, -a/2+1, \cdots, -1 \\ 1/\sqrt{a} & k = 0, 1, \ldots, a/2-1 \\ 0 & others \end{cases} \tag{6}$$

Haar wavelet transform of the GPS-BPSK signal. There will be peaks at the times where phase changes occur. Figure 2(a) gives Haar WT magnitudes of GPS-BPSK signal at $a = 2$, there are distinct peaks on phase change in GPS signal. Figure 2(b) shows Haar WT magnitudes of Gaussian white noise, which still is Gaussian distribution.

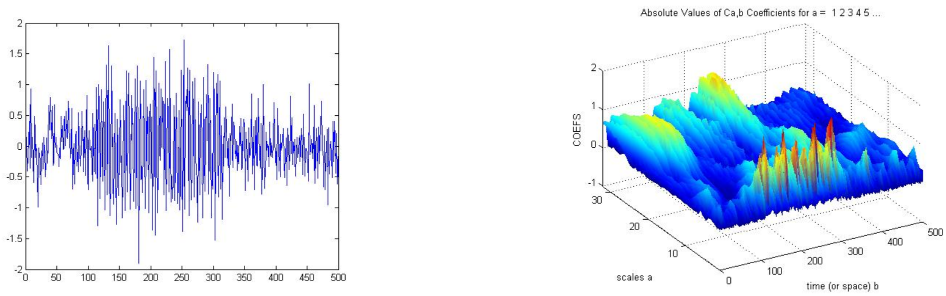


(a) (b)

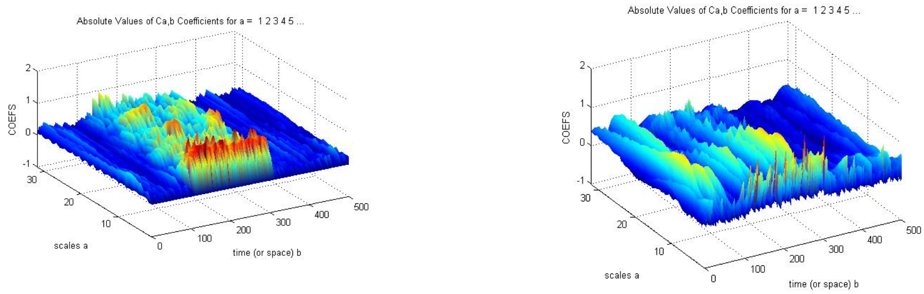
fig. 2 WT magnitudes of signal

4.2 Wavelet spectrum

Wavelet transform spectrum is defined as the WT magnitude squared value, which is an energy distribution on the time-scale domain. When the received signal contains noise only, WT spectrum has no obvious projecting peaks, since the noise energy is uniform distribution. When the primary signal is present, WT spectrum has significantly the peaks.



(a) (b)



(c) (d)

fig 4. WT spectrum of the transient primary user signal, SNR is 2dB

Figure 4(a) shows the transient primary user signal, SNR is 2dB. Figure 4(b) (c) (d) gives Haar WT spectrum, Morlet WT spectrum and Mexican hat of primary user transient signal. When the primary signal is present, WT spectrum has significantly the peaks, which can achieve the detection of the primary user signal. Different WT spectrum has different sensitivity of the primary. For GPS-BPSK signal, Morlet WT spectrum has the highest sensitivity at $a = 2$ .Owing to uncertainties of the primary user signal it is difficult to select an appropriate scaling factor to make WT magnitude value larger. Therefore a reasonable choice of wavelet type and parameters has a great help to improve detection performance, using combination of the variety WT may also improve the detection result.

5. Conclusions

In this paper, GPS-BPSK signals as the research object established based on Matlab software. By comparison to the existing spectrum sensing technology, detection the GPS-BPSK signal by discrete WT algorithm. The WT magnitude is maxima value where phase changes occur. Wavelet scale spectrum is defined as the WT magnitude squared value, which is an energy distribution on the time-scale domain. We have proposed and studied WT spectrum to identity the primary user signal. Simulation results show significant peak in WT spectrum when the primary user signals apparent. The next step will focus on the WT-based satellite receiver, analyzing the performance of optimal detection. This study could provide technical references and support to alleviate scarcity of spectrum in space network.

6. References

1. FCC. ET Docket No 03—222 Notice of proposed rulemaking and order, December, 2003.

2. Sahai A, Hoven N, Tandra R. Some fundamental limits in cognitive radio. Allenton conf. Oil Commun. Control and computing, October, 2004.

3. Reichert J., Automatic classification of communication signals using higher order statistics [J]. IEEE international Conference on Acoustics, Speech and Signal Processing, 1992, V01.5: 221-224.

4. Ho, K.C., Prokopiw, W., and Chart, Y.T., Modulation identification of digital signals by the wavelet transform, IEEE Proc., Radar, Sonar Navig., 2000, 47, pp. 169-176.

5. Hong, L., and Ho, K.C., Identification of digital modulation types using the wavelet transform. Proc. IEEE MILCOM, 1999, PP. 427-431.

6. A Constantinescu R Jr, Landry I Ilie. Hybrid GPS/Galileo/GLONASS IF Software Signal Generator [C]// ION GNSS 18th International Technical Meeting of the Satellite Division, 13-16 September 2005, Long Beach, CA, USA : 1233-1244.

7. Olivier Julien, Bo Zheng, Lei Dong, Gérard Lachapelle. A Complete Software-Based IF GNSS Signal Generator for Software Receiver Development [C]// ION GNSS 17th International Technical Meeting of the Satellite Division, 21-24 September 2004, Long Beach, CA. USA: 2146-2157.