Research on Technology of LPI / LPD Communication

Wang Tongxiang
Institute of communication engineering
PLA university of science and technology
Nanjing, China
e-mail: 15951710635@163.com

Zhang Yu
Institute of communication engineering
PLA university of science and technology
Nanjing, China

Fan Jianhua
Nanjing telecommunication technology institute
Nanjing, China

Abstract—The LPI/LPD communication is a technology of hiding the information into the noise or other useless signals through an efficient modulation, making it difficult for the detector to capture the hidden information. Spread-spectrum communication has good characteristics of LPI/LPD and has been widely used. Firstly, this paper introduces the technology of spread spectrum communication and then summarizes the existing methods of detection in detail. The quality factor is introduced to give an effective evaluation for the performance of interception. There are so many methods to design the waveform, which has good characteristics of LPI/LPD. This article focuses on the analyzing of the chaotic transform and wavelet transform. Finally the develop trends of the LPI/LPD communication were discussed.

Keywords- spread-spectrum; cyclostationary; high-order volume; chaos; wavelet

I. INTRODUCTION

In the late 1970s, Siefker studied on the stealth radar about the technology [1] of LPI, precluding the study of the LPI theory. Since then, the technology of LPI in the field of radar communication had developed rapidly, arising people's concentrates on the LPI theory. The further research and development of LPI theory had promoted its widely used in many areas. The modern communication systems, which have the character of confidentiality, are increasingly adopting the technology of LPI.

The communication of LPI / LPD (low probability of intercept/low probability of detection) is the technology of hiding the information into the noise or other useless signals through an efficient modulation, making it difficult for the detector to capture the hidden information. It can be divided into direct sequence spread spectrum (DS), frequency hopping (FH), time hopping (TH) and the combination of the above. The DS and FH are most widely used.

The LPI characteristic of spread-spectrum communication is based on the Shannon formula of the information theory:

$$C = B\log_2(1+S/N) \quad (1.1)$$

In the Eq.1, C is the channel capacity of the system (the maximum transmission rate), B is the bandwidth of the channel, S is the average power of the signal, N is the noise power. Shannon formula determines the relationship among the channel capacity, bandwidth and SNR. If the channel capacity is determined, you can reduce the SNR by increasing the bandwidth. This can be used to secure communication.

II. THE TECHNOLOGY OF SIGNAL INTERCEPTION

A. Energy Detection

Energy detection, which is called energy radiometer, is a method of determining whether the information exists through setting the appropriate threshold, which is based on the energy of the signal and noise. Urkowitz, Snow, Edell and Nicholson[2] proposed an method to improve the performance of the energy detection. When the signal is present, the decision statistic has a non-central chi-square distribution with the same number of degrees of freedom and a non-centrality parameter λ equal to the ratio of signal energy to two-sided noise spectral density.

Energy detection is the best method without any priority knowledge. The disadvantage is that it can't detect the parameter of the signal. Another disadvantage is that the detection performance is greatly reduced if some strong interference noise existed. Meanwhile, with the development of LPI/LPD technique, the power spectral density of the transmitted signal can be designed so low that the energy detection is useless.

B. Higher-order Cumulants

The mean and autocorrelation can fully describe the statistical properties of stationary Gaussian processes while they are useless for non-stationary Gaussian process. Stochastic process theory shows that more than third-order cyclic accumulation of the Gaussian noise is 0. Higher-order cumulants of the signal can suppress the

Gaussian noise furthest and then it can detect the parameter of the signal in a weak signal circumstance.

Higher-order cumulants mainly includes higher-order cumulants and its spectrum. The commonly used for the DSSS signal detection and interception is the fourth-order cumulants[3]. The fourth-order cumulants is zero to Gaussian noise while not zero to non-Gaussian noise. Fourth-order cumulants detection can suppress Gaussian noise greatly. According to this characteristic, the high-order cumulants can detect the parameters of the signal.

The high-order cumulants is proved to be an efficient method for the detection of the signal. Li Peng [4] proposed a improved method, which combines the high-order cumulants and the matched filter, showing that the probability of detection signal is increased. Zhang Xiaolin, Tong Jin[5] proposed a method for the detection of the DS-SS/BPSK signal, which is based on the fourth-order statistics 1-D slice C (0,0,r). This method takes the advantages of time-domain and square multiplier into account and it can simultaneously estimate the carrier frequency and the cycle of spreading code. But in the environment, which includes complex noise, the performance of this method decreases.

C. Cyclostationary Analysis

Most signals have the characteristic of cyclostationary. The cyclostationary analysis proved to be an effective detection method. Gardner [6] established the framework of the cyclostationary theory for the first time and then he demonstrated that its performance is superior to energy detection. Since then, many researchers gave a further discussion on the cycle spectrum theory. They proposed a lot of new methods based on the cyclic spectrum theory to detect the signal.

If the autocorrelation of a random signal $x(t)$ is periodic, which satisfies the formula（2.3.1）, $x(t)$ is called periodic stationary signal.

$$R_x(t,t+\tau)=R_x(t+T,t+T+\tau) \tag{2.3.1}$$

The Fourier transform of $R_x(t,t+\tau)$ is:

$$R_x(t,t+\tau)=\sum_{\alpha}R_x^{\alpha}(\tau)e^{j2\pi\alpha\tau} \tag{2.3.2}$$

$$R_x^{\alpha}(\tau)=\frac{1}{T}\int_0^T R_x(t,t+\tau)e^{-j2\pi\alpha\tau}d\tau \tag{2.3.3}$$

If $x(t)$ meets the iterated conditions, the average time can be used to replace the statistical average:

$$R_x^{\alpha}(\tau)=\frac{1}{T}\int_0^T x(t)x^*(t+\tau)e^{-j2\pi\alpha\tau}dt \tag{2.3.4}$$

$x(t)$ is claimed to be the signal of cyclostationarity, $(\alpha\neq 0)$ is called cyclic frequency. $S_x^{\alpha}(f)$, which is being called cyclic spectral density, is the Fourier transform of the $R_x^{\alpha}(\tau)$:

$$S_x^{\alpha}(f)=\int R_x^{\alpha}(\tau)e^{-j2\pi f\tau}d\tau \tag{2.3.5}$$

Gaussian white noise is a random stationary signal. The mean and autocorrelation of the signal is constant, which doesn't have the characteristic of cyclostationary. when $\alpha\neq 0$,the corresponding spectral density is zero. The spectral density is not zero to the signal which has the characteristic of cyclic spectral density.

Cyclostationary analysis is the most common method of signal detecting. It has good performance, but the disadvantages are also existed. Something like no real-time, system complexity, large amount of calculation and so on. Liu Shuai[7] proposed a frequency-domain design methodology for the detection of the cyclostationary feature according to the character of the Fourier transform. It proved to be an effective method. Wang Manxi[8] proposed TSAE-Z algorithm which combines the autocorrelation envelope and Zoom-FFT of variable step. The algorithm has good characteristic of low calculation and its performance improves 6dB.

III. ANALYSIS OF SIGNAL INTERCEPTION PERFORMANCE

In order to evaluate the Interception performance of the LPI/LPD signals, Lawrence L. Gutman[9] proposed the quality factor to evaluate signal interception performance. It provides a basis method to evaluate the performance of signal interception. The quality factor is acquired by the analysis of the antennas, modulation schemes, atmospheric propagation and interference. Define the quality factor:

$$\begin{aligned} Q_{LPI} &= 20\log(\frac{R_c}{R_i}) \\ &= Q_{ANT}+Q_{ATM}+Q_{MOD}+Q_{ADA} \end{aligned} \tag{3.1}$$

$Q_{ANT}, Q_{ATM}, Q_{MOD}, Q_{ADA}$ is defined:

$$Q_{ANT}=10\log(\frac{G_{tc}G_{ct}}{G_{ti}G_{it}}) \tag{3.2}$$

$$Q_{ATM}=\xi R_i-\xi R_c \tag{3.3}$$

$$Q_{MOD}=10\log(\frac{S_i/N_{oi}}{S_c/N_{oc}}) \tag{3.4}$$

$$Q_{ADA}=10\log[\frac{kT_{ai}+T_0(F_i-1)+\sum_{n=1}^{N}\sum_{m=1}^{M}g_{in}g_{im}\frac{J_{nmi}}{B_i}}{kT_{ac}+T_0(F_c-1)+\sum_{n=1}^{N}\sum_{m=1}^{M}g_{cn}g_{cm}\frac{J_{nmc}}{B_c}}] \tag{3.5}$$

Q_{ANT} is identified as the antenna quality factor, Q_{ATM} is identified as atmospheric propagation quality factor, Q_{MOD} is identified as modulation quality factor, Q_{ADA} is identified as adaptive technology quality factor. The quality factor gives a comprehensive analysis of the factors that affecting the signal transmission. It carries out quantitative description for the evaluation of

the signal interception performance and has been widely used.

IV. The Technology of LPI/LPD in Direct Sequence Spread Spectrum Communication

In the spread-spectrum communication, DSSS uses a high pseudo-random bit-rate code to modulate the signal. Its function is to modulate the signal into broad band and decreases the power spectral density. HF uses a pseudo-random code to control the selection of the carrier frequency. HF gets higher RF power in a narrow band and thus has poor performance in signal detection. DSSS gets better LPI performance. In modern covert communications, DSSS is widely used.

In order to improve the LPI/LPD performance of the signal, the attraction is concentrated on the designing of better pseudo-random sequence. The sequences that widely use are m-sequence, Gold sequence, Kasami sequence and chaotic sequence. The m-sequence has good properties of autocorrelation, but the cross-correlation has bigger side lobes. Gold sequence has good properties of correlation, but the randomness is poor. The chaotic sequence with non-periodic has ideal autocorrelation and cross correlation properties. It also gets widely used in the LPI/LPD communication. In the transform communication, Richard, Thomas[10] proposed the LPI/LPD technology based on wavelet transform. It proved to be an efficient modulation. They used Harr wavelet and Daubechies wavelet to conduct the experimental simulation. The I/Q and constellation diagrams have good Gaussian performance. With great flexibility and diversity, the signal transmission power and the cyclostationarity of the signal can be reduced by a reasonable choice of wavelet function. In the LPI/LPD communication, the study on the wavelet has just stay initial stages. Many excellent properties of wavelet used for LPI/LPD communication have not been studied.

A. The Technology of LPI / LPD communication Based on Chaotic Transform

Chaotic sequence is very sensitive to initial conditions. With long-term behavior unpredictability and aperiodic, the chaotic sequences are widely used in signal designs. Zhang Shenru [11] conducted a test on the uniform, correlation, linear complexity of the chaotic modulation. The results show that chaotic transform has excellent randomness and high complexity. It proved to be good LPI/LPD characteristics. Currently the main mapping methods include Logistic-Map mapping, Kent maps and Chebyshev mapping.

Through the mapping, it can produce a large number of non-periodic sequences. The good characteristic of pseudo-random in the chaotic transform is the reason that it has been widely used in the spread-spectrum communication. The chaotic sequences improve the LPI/LPD performance of the spread-spectrum communication. However, the chaotic sequences show the best characteristic only in the infinite length and high precision state. In practical applications, the chaotic sequences must be intercepted. The autocorrelation and cross-correlation properties decrease. Because of the complexity and uncertainty, chaos theory hasn't been fully studied. The research on the chaotic theory concentrates on improving the complexity and performance of the chaotic sequences.

On one hand, many researchers have created a lot of new ideas to improve the performance of the chaotic sequences existed. Zhang Xueyi[12]proposed a method, which was based on the Logistic-Map linear transformation. The results of simulation show that this method can produce more chaotic sequences. It also increased the concealment of the transmitted signal. An Chengquan[13] proposed a method that generating sequences of binary chaotic that had been multi-stage quantified. This method improved the self-correlation and cross-correlation of the signal. Kang Shouqiang[14] designed a modified circuit called Cai. It could produce rich chaotic behavior. Bao Haoming[15] constructed a piecewise parabolic map. It had constructed the chaotic sequences satisfactorily. On the other hand, with the development of chaos theory, many researchers proposed many new chaotic systems. Cai Guoliang[16] proposed a new chaotic system, which is called the switching chaotic and hyperchaotic system. The performance of this new chaotic system is better than the previous chaotic system. It greatly improved the security of information. Yuan Liping [17] designed a new switching chaotic system based on the nonlinear Lorenz system. The new system improved the LPI performance of the signal on the number of chaotic sequence mapping and the adjusted range of the parameters.

There are many complex problems that waited to be resolved in the chaos theory. With the improvement of the chaos theory, it will play a more important role in the communication field, especially in the LPI/LPD communication.

B. The Technology of LPI/LPD Communication Based on Wavelet Transform

Richard and Thomas have surmised the characteristics of the LPI/LPD signal. The characteristics of the LPD signal: (1) Gaussian marginal distribution; (2) complex Gaussian marginal distribution; (3) higher order moments. The characteristics of the LPI signal: (1) pulse autocorrelation; (2) white power spectrum; (3) low power; (4) Low power spectral density; (5) lacking of cyclostationary features; (6) lack of repetition. And then the wavelet transform was applied to the LPI/LPD communication. At first, they realized the pure modulation using Harr wavelet. The I/Q and constellation maps showed good LPI/LPD properties. Subsequently, they established the communication system based on wavelet transform. The Daubechies wavelet is applied to the system. The simulation showed that I/Q and constellation diagrams had good LPI/LPD properties. Meanwhile, it has decreased the cyclostationary of the signal. So far, there aren't any further studies on the wavelet that used in the LPI/LPD communication.

The wavelet has many good properties that can be used in communication. In LPI/LPD communication, it can produce the sequences without obvious cyclical characteristic and sequences with low cyclostationary. Besides, the computational complexity of wavelet is low. These good characteristics are acquired by its flexibility and diversity. In 1910, Harr conducted the first wavelet that called Harr wavelet. Its calculation is simple. Since then, the wavelet has gotten great development. The Morlet wavelet has good characteristic of locating in time and frequency. The Daubecheies wavelet is orthogonal or biorthogonal.The spline wavelet is used in curve fitting. The study of wavelet used in the LPI/LPD communication is still staying in the beginning stages. The excellent features of various wavelets will make contributions to the LPI/LPD communication.

V. CONCLUSIONS

The technology of LPI/LPD communication includes signal designing, signal interception and the evaluation for the signal interception performance. The spread-spectrum technique is widely used in the LPI/LPD communication, especially the DS. In the DSSS, m sequences, Gold sequences, Kasami sequences and chaotic sequences are widely used. The chaotic sequences, which is non-periodic and sensitive to the early value, is further discussed in the article. It proved to be better than the other pseudo-random sequences. In the transform communication, wavelet transform has been used to produce signals with good LPI/LPD characteristics. The study on the application of wavelet hasn't been enough and there are many jobs reserved to be done. The technology of signal interception includes energy detection, higher-order cumulants, cyclostationary analysis, time-frequency analysis. The quality factor is used to evaluate the interception performance of the LPI/LPD signals.

The accurate and reliable information plays key role of the modern wars. In the communication, the concealment of information is especially important. The development of the LPI/LPD technology becomes more and more important. It plays an important role in the national security field. With the development of the LPI/LPD technology, The wavelet transform and chaotic sequences will play an important role in the communication.

REFERENCES

[1] Siefker R.G.The intercept of covert radar[J].Military Electronics/Countermeasures,1979,5:56.

[2] H.Urkowitz. Energy detection of unknown deterministic signals. Processdings of the IEEE,1967,55(4):523-531.

[3] Chong-Yung chi,Chih-Chun Geng.Blind Channel Estimation and MMSE Equalization Using Shalvi and Weinstein's Blind Deconvolution Criteria. Proc.IEEE Wireless Communication and Networking Conference,New Orleans,LA,1999,Sept.21-24,p.659-663.

[4] .Li Peng, Chen Gang. A new method for the detection of high order cumulants and matched filtering of the.Aerospace Elecctronics Information Engineering and based on Control, 200628 (1).

[5] Zhang Xiaolin, Tong Jing, Li Youhu. A new method for detection of m sequence analysis of high order statistics. Harbin Engineering University School of information and communication engineering, Heilongjiang Harbin 1500012011.

[6] W.A.Gardner,C.M.Spooner. Cyclic spectrum analysis for signal detection and modulation recognition,1988,Military Communications Conference,Vol.2:419-424.

[7] Liu Shuai. Study on detection of noise ratio estimation of frequency domain design and signal cyclostationarity. Application of electronic technique 36 (.2010 2).

[8] Wang Manxi. A fast and effective method of cyclostationary signal detection. Journal of National University of Defense Technology,.2007 29 (5).

[9] Lawrence L.Gutman.System Quality Factors for LPI Communication.Systems Engineering, 1989.IEEE International Conference,1989,475-478.

[10] R Orr,C Pike.Covert communications employing wavelet technology.Signal, System and Computers,1993.Conference Record of The Twenty-Seventh Asilomar Conference on.Vol.1,523-527.

[11] Zhang Shenru, Wang Tingchang, Deng Xiaoyan. The set [C]. Nanjing anti-jamming technology academic paper statistics monitoring [A]. military communications FH code sequence: the 63 Research Institute, 1997.188-193.

[12] Zhang Xueyi,Jin Lu.Logistic-Map Chaotic Spreading Spectrum Sequence Under Linear Tranformation.Intelligent Control and Automation,2000.Proceedings of the 3rd World Congress on.2000,Vol.4,2464-2467.

[13] An Chengquan,Zhou Tingxian.Design of Chaotic Spread-spectrum Sequence with Good Correlation Properties for DS/CDMA.Circuits and Systems,2003.ISCAS '03.Preceedings of the 2003 International Symposium on.2003,Vol.3,104-107.

[14] Kang Shouqiang. Chaotic Chua's circuit. Electric machines and control, 200913 (6).

[15] Bao Haoming, Zhu Yisheng. The chaotic secure communication system based on hierarchical key. Dalian Maritime University School of information science and technology, Dalian, Liaoning in 1160262011.

[16] Cai Guoliang, Tan Zhenmei, Zhou Weihuai. Dynamic analysis and chaos control and synchronization of a new chaotic system. Journal of physics.2007, 56 (11): 6230-6237.

[17] Li Ping; research on [D] ultra wideband wireless communication based on chaos; Hangzhou Dianzi University; 2011.