Transient Signal Feature Extraction Based on Box Dimension and the Largest Lyapunov Dimension

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***Abstract*—Cognitive radio is one kind of wireless communication technology, which is to effectively improve the spectrum efficiency by the way of wireless spectrum sensing. Besides of varieties of security issues of the traditional wireless communication, it also has some new problems, such as Primary User Emulation (PUE) attack. This essay presents that based on the fractal dimension of the transient signal characteristics extraction to protect the PUE attack from the cognitive wireless networks, and then extract the fractal dimension of wireless transmitter through experiments to provide reliable characteristic parameters for the next signal recognition, finally to prevent PUE's attack.**

Keywords- cognitive radio; primary user emulation attacks; box dimension; the largest Lyapunov dimension; feature extraction component

I. INTRODUCTION

Cognitive radio network is a new communications network which is developed on the base of software radio. Accessing the authorized band in a "chance", it will take advantages of the temporary idle band dynamically, then to optimize the spectrum efficiency[1]. In Cognitive radio networks, a licensed user is called Primary User (PU), and unlicensed user is called cognitive user. Radio spectrum sensing is one of the key technologies of Cognitive radio networks. Its purpose is to find out the spectrum hole which is not being utilized by user currently in radio spectrum. It is also for testing the existence of the primary user signal, and it is also the premise assurance of the property work of cognitive radio[2]. Cognitive radio networks has been paid extensive attention and distinguished developed since Dr. Mitola, from Swedish Royal Institute of Technology in 1999, firstly proposed the concept of cognitive radio[3].

As one kind of radio communication, cognitive radio will come through not only some security issues of traditional radio communication, but also some new security problems, such as the PUE attack, ect. PUE attack will send a primary user emulated signal in the authorized spectrum bands to deceive the cognitive user, thereby preventing the cognitive user accesses these bands, then to achieve the purpose of illegal possession of spectrum resources. The PUE attack will not only seriously disturb the spectrum cognitive process of cognitive user, but also seriously reduce the available spectrum resources of cognitive user[4]. This paper introduces the concept of Specific Emitter Identification, SEI, which is for the identification of non-cooperated equipment in cognitive networks and achieving the purpose of PUE attack prevention. The study of SEI mainly has the process of Local Oscillator Phase Noise extraction, transient signal "fingerprint" recognize, cyclic spectrum characteristics extraction, clock fingerprint extraction, and so on. This paper will start from the transient signal "fingerprint" recognize. Working from static status to work status, the transmitter will experience a transient process, of these characteristics, such as amplitude and phase, are specialized by each transmitter. The transient signal fingerprint recognize will analysis and extract those features, and then being identified as the basis of the user transmitter "fingerprint" recognize. This paper presents a transient signal based on fractal theory "fingerprint" characteristic extraction, as the basis of the PU transmitter identification.

II. THE FRACTAL THEORY AND FRACTAL DIMENSION

The fractal theory was first proposed by B.B.Mandelbort in 1967, which is to describe irregular and chaotic things and phenomena of nature. There are series of fractal characteristics of objects in the nature, such as the coastline, the shape of lightning, the folds of the brain and the shape of the snowflake, etc., which have a common characteristic of self-similar between the part and the whole. The maim fractal research tool is its dimension. The fractal dimension objects can be described by the fractal dimension. It quantitatively describes the shape and complexity of fractal objects. There are various fractal dimension defined methods, such as the Hausdorff dimension, information dimension, capacity dimension, etc. This paper is to expand the box dimension and the largest Lyapunov dimension, for providing recognized basis of cognitive radio signal extracting the box dimension and largest Lyapunov dimension. Let $A \in Rn$, under the euclidean distance, N (δ, A) represents the minimum number of δ sets , required for covering the set A required maximum diameter of the minimum number of the box counting dimension definition [3] is:

$$D_B = \lim_{\delta \to 0} - \frac{\ln N(\delta, A)}{\ln \delta} \quad (1)$$

D_B is the set A box dimension. Box dimension is very easily calculated by the computer, so it is by far the most common fractal dimension, is widely used in various disciplines.

This article is based Wolf[5] to calculate the maximum Lyapunov dimension. The Wolf method is based on the phase space reconstruction. In the phase space reconstruction process, the most important step is to determine the delay time τ and embedding dimension m, of which choices is directly related to the quality of the phase space

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reconstruction. This paper takes use of a simple algorithm based on the correlation integral to simultaneously estimate the delay time and embedding dimension. This method is improved by H.S.Kim et al, called the C-C algorithms[6]. The Wolf method uses delay to phase spaces reconstruct the transient signal time series x (t) firstly. The delay time τ and embedding dimension m is determined by the C-C algorithm. Each point in space by {x(t), x(t+τ), ..., x(t+(m-1)τ)} are given. Identify the points nearest to the initial points {$x(t_0)$, $x(t_0+\tau)$, …, $x(t_0+(m-1)\tau)$}. Identify the distance between these two points by $L(t_0)$. To the time of t_1, the value of $L(t_0)$ evolves to the value of $L'(t_1)$, then in accordance with principle of the distance of fiducial point, $L(t_1)$, and the intersection angle between $L(t_1)$ and $L'(t_1)$ to be wee to look for a new data point until exhaust all of the data points in this way. The maximum Lyapunov dimension obtained index λ_1:

$$\lambda_1 = \frac{1}{t_p - t_0} \sum_{k=1}^{p} \log_2 \frac{L'(t_k)}{L(t_{k-1})} \qquad (2)$$

Where P is the total number of evolution, when λ_1 tends to be stable, the maximum Lyapunov dimension calculates successfully.

III. THE EXPERIMENTS AND RESULTS ANALYSIS

For WLAN network, we have established a signal acquisition system shown in Figure 1. Two USB wireless network cards are installed on PC1 and PC2 transceiver 802.11b wireless signal (The signal element rate 11Mbps) separately. The distance between the two PC is about 5 meters. When the two NIC successfully establish a radio link and start to transmit and receive the signal, the oscilloscope will receive signal in the location closed to the transmitting position relying on external a 2.4GHz omnidirectional antenna. In this experiment, we used the Agilent Infiniium DSA91304A high-performance oscilloscope (13GHz bandwidth, 4 analog channels, the sampling rate of each channel can be of reach 40Gsa/s).

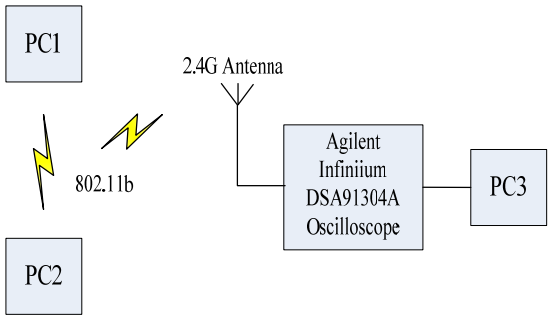

Figure1. Wireless Signal Acquisition System.

According to the Wireless signal acquisition system on Figure 1, we collect six different brands of network cards (NIC) signals. Each NIC collects 10 sets of data. Firstly, doing the Hilbert Transform on the wireless LAN signal x (n) collected, then extracting the data development of the transient parts, as shown in Figure 2, we will see the obvious differences of the transient preamble response between several NIC bands. Therefore, we can proceed fractal feature extraction on the transient preamble response of the radio signals.

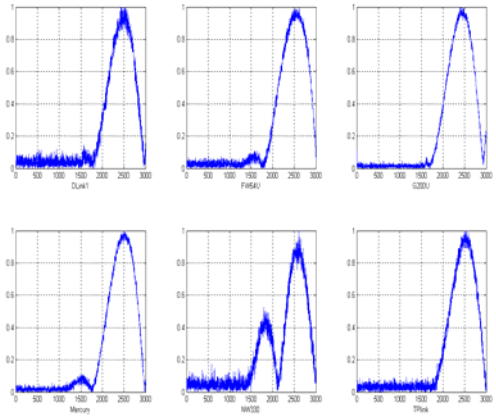

Figure1. the Data Development of the Transient Part from Radio Signal.

Figure 3 is a process flow of the transient signal. It is the process of Wireless LAN signal envelope extraction, the starting point detection and interception of a section containing the noise signal, the leading response signal and the useful symbol in response to the signal (2000 points totally, 200ns, 500 points before the starting point, 1500 points after the starting point).

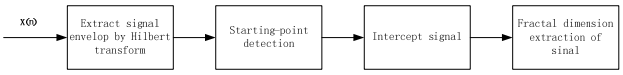

Figure3. Transient Signal Processing Flow.

In Figure 3, for the starting point detection processing, we take measure of short-term energydectection. The short-term energy is the results of the signal transmitting through the digital filter of which impulse response h (n). It is usually defined as

$$E_n = \sum_{k=-\infty}^{+\infty} [x(k)g(n-k)]^2 \qquad (3)$$

Where, $h(n) = g^2(n)$ is a function of the analysis window, rectangular window function and the Hamming window function. The rectangular window function is used in this article to derive the short-term energy En for data x(n), then based on the energy detection threshold to determine the transient starting point. Once having determined the starting point, the interception of a signal should be obtain, and the signal should be done fractal characteristics extraction.

Firstly, extract the box dimension of the signals, set the grid number of 218 to ensure that it can cover all of the signals. Use Matlab programming to extract the box dimensions from six NICs, then to describe it intuitively by plot point function. As shown in Figure 4. the same brand of cards box dimension has good clustering, and the different brands of box have some certain diversities.

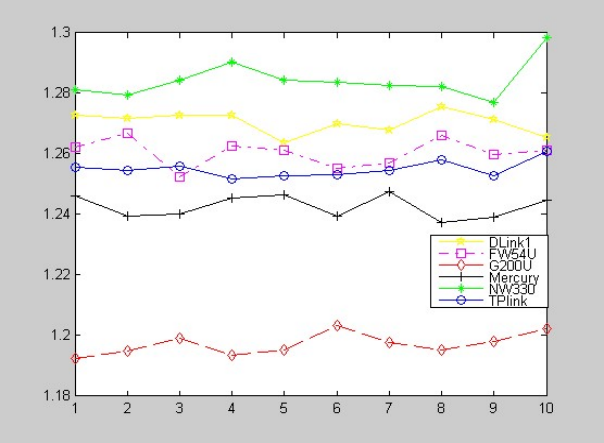

Figure.4 Different Brand Card Box Dimension.

By Wolf method, calculating the largest Lyapunov dimension, firstly use the C-C algorithm to determine the delay time τ and embedding dimension m. In case of TPlink card signal, using Matlab software programming, make Scor (t), $\overline{s(t)}$, $\Delta\overline{S(t)}$ graph related of t, as Figure 5 shows. The delay time τ is t corresponding the first minimal value of $\Delta\overline{S(t)}$; delay time window τ_W is t corresponding the minimal point of Scor (t) . In Figure 5, τ = 12, τ_w = 12, embedding dimension m = τ_W/τ +1, by calculating, the embedding dimension m, m = 2. After determining the delay time τ and embedding dimension m, by Wolf method, calculate the largest Lyapunov dimension of six different brand NIC signal and then depict stippling, as shown in Figure 6.

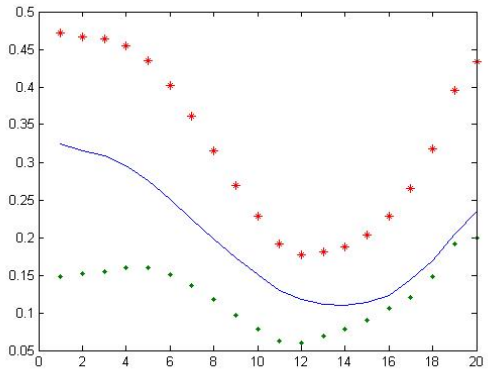

Figure5. The C-C Algorithm Figure of TPlink NIC Signal.

In Figure 6, the largest Lyapunov dimension of the same brand card signal still has a good clustering, and different brand of NIC signals also have some diversities. But from the largest Lyapunov dimension of 3 brands of FW54U，G200U and Mercury, the difference is quite small.

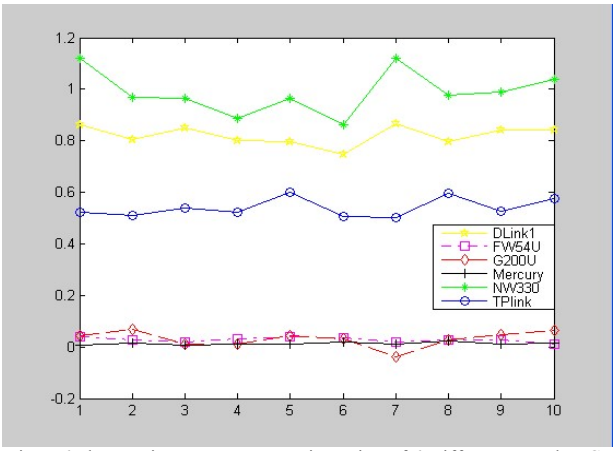

Figure6. the Maximum Lyapunov Dimension of 6 Different Brand NIC Signal.

IV. SUMMARY

Cognitive radio is a spectrum sensing to improve the spectrum efficiency of radio communication technology. PUE attack has been a major factor in troubling cognitive radio security issues. This paper presents extraction based on the fractal dimension of the transient signal characteristic, providing the characteristics parameters for the main the user signals identifying, to achieve the purpose of prevention PUE attack. Through the acquisition of wireless LAN signal, and its series of processing to extract the box dimension and the largest Lyapunov dimension. On the view of the results, the dimension of the same brands of NIC has a good clustering, and the different brands NIC have some diversities. As to identify the characteristics of the input parameters, the box dimension effect is superior to the maximum Lyapunov dimension.

REFERENCES

[1] Hong RONG. A Detection Method of Primary User Emulation Attacks in Cognitive Radio. Industry Observe, col. 6, pp. 54-58, 2012.

[2] HAYKIN S. Cognitive Radio: Brain-Empowered Wireless Communications[J]. IEEE J. Sel. Areas Commun,2005, 23(2):201-220.

[3] Mitola J, Maquire G J. Cognitive radios: making software radios more personal[J]. IEEE Personal Communications, 1999, 6(4):13-18.

[4] Sangiorgi D, Walker D. The π-calculus: a Theory of Mobile Processe[M]. Cambridge University Press,2001.

[5] Wolf A , Swift J B , Swinney H L , et al. Determining Lyapunov exponents from a time series [J] . Physica , 1985 , 16D : 185.

[6] Kim H S, Eykholt R, Salas J D. Nonlinear dynamics, delay times, and embedding windows[J]. Physica D, 1999, 127: 48-60.