Performance of Efficient Signal Detection Scheme for Heterogeneous Network Structure

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Abstract. In this paper, we proposed and analyzed the novel spectrum sensing scheme by employing the digital watermarking technique in cognitive radio (CR) system. CR technique which is proposed as a technology that utilizes the frequency resources effectively, has studied to relive scarcity of the frequency resources. CR provides opportunistically under-utilize licensed frequency to the secondary user. Also, heterogeneous network has emerged as a promising solution for areal capacity gain and coverage improvement of broadband wireless access service. However, the heterogeneous network, which uses the same frequency band, can cause co-channel interference. Under this condition, in this paper, we provide advanced signal detection scheme to detect signals, which use same frequency band. Results of this paper show the high detection probability in heterogeneous network structures.

Keywords: Cognitive radio, heterogeneous network, digital watermarking scheme, detection probability, false alarm probability

1 Introduction

According to wireless technologies have developed rapidly, more spectrum resources are needed to support considerable and various wireless services. However, limited spectrum resources are regulatory assigned to licensed user and any interference cannot allow to unlicensed user. Also, a recent survey of the spectrum utilization made by Federal Communications Commission (FCC) has indicated that the actual licensed spectrum is largely under-utilized in vast temporal and geographic dimensions [1]. In order to relieve the spectrum scarcity and inefficient spectrum utilization, cognitive radio (CR) was recently proposed [2-4].

CR, proposed by J. Mitola in 1999 [5], is a promising approach to achieve open spectrum sharing flexibly and efficiently [2-3]. The FCC is reviewing its policies regarding the usage of unused TV bands for unlicensed user access [6, 7] along with several other projects inclusive of the Next Generation (XG) program [8] by Defense Advanced Research Projects Agency (DARPA) and the NeTS-ProWin project [9] by national science foundation indicate a paradigm shift in the frequency regulation.

The heterogeneous network has emerged as a promising solution for areal capacity gain and coverage improvement of broadband wireless access service [10]. In the case of frequency resources are shorted or limited, heterogeneous network can fully reuse the frequency band which is being used in the macro-cells and femto-cells. Therefore, all device or system in the macro-cells and femto-cells share the same frequency and the highest frequency reuse gain is achieved [11-12]. However, the heterogeneous network, which uses the same frequency band, has a problem such as co-channel interference which is a major issue that limits the performance of the network. Especially, co-channel interference between macro-cells and femto-cells is even more prominent problem in heterogeneous network [13].

For this reason, in this paper, we provide advanced techniques with digital watermarking sequence to detect signals, which use same frequency band such as between macro-cells and femto-cells. Digital watermarking techniques can be applied to many digital communication systems with various objectives. Digital watermarking based on a spreading sequence is the most promising scheme among the watermarking methods in wireless fading channels due to its robustness of noisy environment.

There are some advantages of proposed algorithm as follows. First, the signal detection complexity is lower than the conventional energy detection or signal feature detection. Finally, as the proposed algorithm uses the autocorrelation property of the digital watermarking sequence, it has the better signal detection probability than conventional sensing algorithm with low detection threshold at each false alarm (FA) probability.

The rest of the paper is organized as follows. Section 2 introduces the proposed system model and Section 3 shows the simulation results and discussions. Finally, Section 4 draws some conclusions of the paper.

2 System Model

Fig. 1 shows the block diagram of an advanced signal detection technique with digital watermarking sequence for heterogeneous network. Each primary user's data is mapped with m-ary phase shift keying. And then, mapped data is modulated to the target bandwidth by modulator.

Finally, digital watermarking sequence is added up to the modulated data. In this paper, we use a Kasami sequence as a digital watermarking sequence due to its good auto/cross correlation properties.

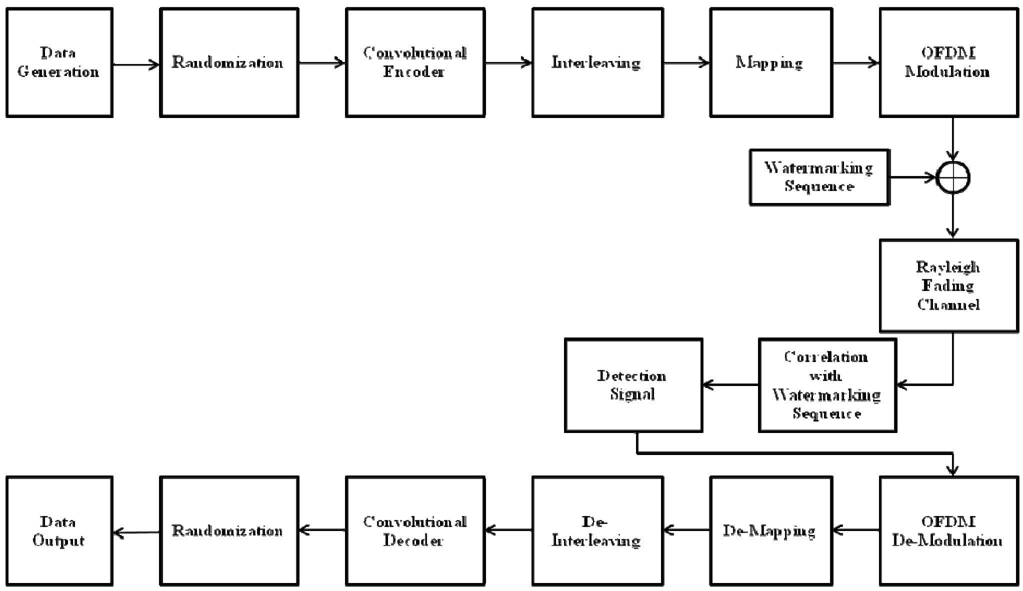

Fig.1. Block diagram of the proposed algorithm

In the block of adding a watermarking sequence, first, selected digital watermarking sequences are added up onto transmit data of each sensor. At this time, the digital watermarking sequence has the power level about -5dB ~ -20dB lower than transmit signal power for maintaining system performance compared with that without digital watermarking system.

At the receiver, a log-likelihood function of received signals is given by

$$L(S) = \ln p\left(r(n)\right), \tag{1}$$

where $r(n)$ is received signal and $p\left(r(n)\right)$ denotes probability density function (PDF) of $r(n)$. From (1), we obtain maximum likelihood (ML) estimation of S given by

$$\begin{aligned}\hat{S} &= \arg\left\{\max_{S} L(S)\right\}, \\ &= \arg\left\{\max_{S} \sum_{n=0}^{i-1} \ln\left(p\left(r(n)\right)\right)\right\},\end{aligned}$$

$$= \arg \left\{ \max_{S} \sum_{n=0}^{2i-1} r(n) w(\tau - n) \right\}, \tag{2}$$

where $w(n)$ is watermarking sequence added up to the transmitter signal. ML estimation finds the maximum output value of the correlator from correlation between the received signal and the watermarking sequence.

3 Performance Analysis

In this section, we analyze the performance of false alarm (FA) probability and misdetection probability of the proposed algorithm with digital watermarking sequence.

It is assumed that each primary user's signal to be digital watermarked $x(n) \in \mathbf{R}^N$ can be modeled as a random vector which has independent identical distributed (i.i.d) Gaussian random variable with standard deviation σ_x, i.e., $x \sim N(0, \sigma_x)$. And digital watermarking sequence is defined as a direct spreading spectrum sequence $w(n)$, which is a randomly generated as,

$$w(n) \in \{\pm 1\}^N, \tag{3}$$

where N is the length of digital watermarking sequence and $n = 1, 2, \cdots N$. The digital watermarked signal is given by

$$y(n) = x(n) + \delta w(n), \tag{4}$$

where δ is the amplitude of digital watermarking sequence. Finally, the received signal $r(n)$ is given by

$$r(n) = h^i(n) \otimes (x(n) + \delta w(n)) + n(n), \tag{5}$$

where $h^i(n)$ is a complex channel impulse response of the i-th on-body sensor, $\otimes$ denotes the convolution sum, and $n(n)$ is the additive white Gaussian noise (AWGN) with zero mean and variance of N_0.

In Fig. 1, sensing and detection block performs the correlation between received signal $r(n)$ and digital watermarking sequence $w(n)$, and from (2), result of correlation is given by

$$C(r(n), w(n)) = \hat{S} \\ = \arg\left\{\max_{S} \sum_{n=0}^{2i-1} r(n)\, w(\tau - n)\right\}. \tag{6}$$

From (6), false alarm (FA) probability P_{FA} can be expressed by

$$P_{FA} = \Pr\left[\hat{S} \geq \lambda \mid (z(n) = x(n))\right] \\ = \frac{1}{2} erfc\left(\frac{\lambda\sqrt{N}}{\sigma_x \sqrt{2}}\right), \tag{7}$$

where λ is detection threshold and $z(n)$ is a given signal vector.
And, misdetection probability P_{MD} is expressed by

$$P_{MD} = \Pr\left[\hat{S} \leq \lambda \mid (z(n) = r(n))\right] \\ = \frac{1}{2} erfc\left(\frac{(\hat{S} - \lambda)\sqrt{N}}{\sigma_x \sqrt{2}}\right). \tag{8}$$

From (8), detection probability P_D is derived by

$$P_D = 1 - P_{MD} \\ = 1 - \frac{1}{2} erfc\left(\frac{(\hat{S} - \lambda)\sqrt{N}}{\sigma_x \sqrt{2}}\right). \tag{9}$$

4 Simulation Results

In the case of application the digital watermarking sequence for detection and classification of the various heterogeneous network devices, water marking sequence should have low power level that hardly interfere to other devices. As mentioned above section II, digital watermarking sequence levels between -27dB and -39dB have almost same BER performance. So, in this paper, we simulate the detection probability with -27dB, -33dB and -39dB water marking sequence. Also, the simulation is performed according to FA probability level with 2.9%, 4.4%, 6.4%, 8.3% and 10.8%.

Table 1. Simulation parameters.

Simulation Parameters	Value
Modulation Type	16QAM
Channel Coding	Convolutional Coding, 3/4
FFT Point	512
CP Length	1/4
Channel	Rayleigh Fading Channel
Watermarking Sequence	Kasami Sequence
Watermarking Sequence Length	10000
Watermarking Sequence Level	-15dB ~ -39dB

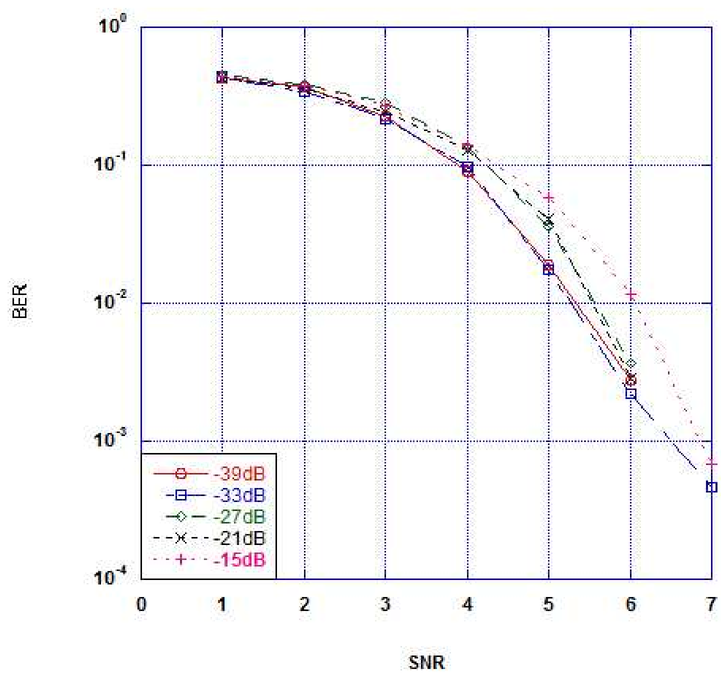

Fig. 2. BER performance with different watermarking sequence level

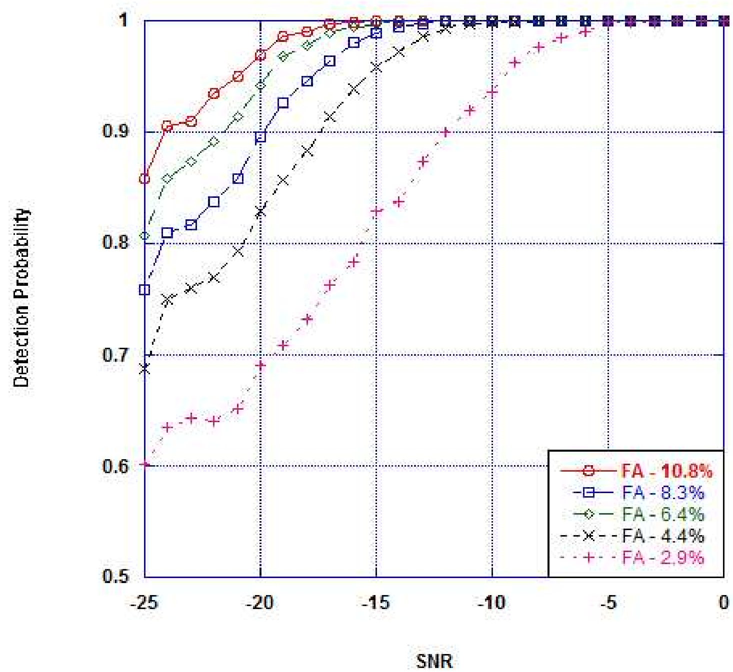

Fig. 3. Detection probability with various FA probability (-27dB level)

Table 1 shows the simulation parameters. We use the Convolutional coding with coding rate 3/4, OFDM modulation with 512 FFT points, and 10000 digital watermarking sequence length.

Fig. 2 shows the bit error rate (BER) performance with different digital watermarking sequence level. In Fig. 2, digital water marking sequence levels between -27dB and -39dB have almost same BER performance.

Fig. 3 shows the detection probability when digital watermarking sequence level is -27dB. X-axis represents signal to noise ratio (SNR) from -25dB and 0dB and Y-axis represents signal detection probability from 50% and 100% range. In Fig. 4, detection probability become higher and higher according to FA probability is getting more and more increased.

5 Conclusions

In this paper, we proposed the advanced signal detection technique using digital watermarking sequence for heterogeneous network systems in co-channel interference environment. From the simulation results, proposed scheme has lower complexity and higher detection probability with low system SNR and very low watermarking sequence level. Simulation results show the detection probability with -27dB digital watermarking sequence when FA probability levels are 2.9%, 4.4%, 6.4%, 8.3% and 10.8%. Also simulation results show that signal detection scheme based digital watermarking sequence has efficient signal detection performance for heterogeneous network which has complex network architecture.

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