Cooperative Spectrum Sensing in OFDM based on MIMO Cognitive Radio Sensor Networks

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***Abstract*— Sharing of frequency spectrum between licensed primary users and unlicensed secondary users (SUs) requires reliable detection of spectrum occupancy by the SUs. We present a a new cooperative spectrum sensing in OFDM system based on MIMO Cognitive Radio (CR) Sensor Networks. We present a new interference temperature estimation approach based on OFDM technique in MIMO system. Frequency spectrum sensing combination of the observed energy values from different cognitive radio users is investigated. Square-law-combining (SLC) is theoretically proved to be nearly optimal in low signal-to-noise ratio (SNR) region, an usual scenario in the context of MIMO cognitive radio sensor networks. Simulation and experiment results show a substantial improvement for the utilizations of frequency spectrum of SUs.**

Keywords- Frequency spectrum sensing; estimation; OFDM; MIMO

I. Introduction

Frequency spectrum is a scarce resource which generally is regulated by governmental agencies. Traditional spectrum management is rather inflexible with exclusive licenses for the use of specific frequency bands. Despite all the frequency bands being already allocated, recent measurements indicate low spatial and/or temporal utilization of parts of the licensed spectrum [1]. The demand of radio-frequency spectrum is increasing to support the user needs in wireless communication. FCC report [2] suggests that many portion of radio spectrum are not in use for significant period of time and use of these "spectrum holes" can be increased significantly. Cognitive radio (CR) [3] enables much higher spectrum efficiency by dynamic spectrum access[4-5]. Therefore, it is a potential technique for future wireless communications to mitigate the spectrum scarcity issue. A CR user acts as a secondary (unlicensed) user and is allowed to utilize a spectrum band only when it does not cause interference to primary (licensed) users, which entails continuous spectrum sensing in MIMO CR sensor networks. Therefore, it becomes a critical issue in cognitive radio to detect the presence of primary signals reliably and quickly[6].

Cognitive radio transmits on a piece of spectrum found not utilized by the primary user (PU). Subsequent transmission from CR should not cause interference to primary user when PU starts using previously unused spectrum. Spectrum sensing is a tough task because of shadowing, fading, and time-varying nature of wireless channels. This results in low signal-to-noise ratio (SNR) condition at the CR input, and makes CR fails to detect primary user and begins transmission, thereby causing potential interference to the primary user. To combat these effects, cooperative spectrum sensing schemes have been proposed to take advantage of the spatial diversity in wireless [7]-[10]. In cooperative spectrum sensing, information from different CR users is combined to make a decision. In [8] and [10], only conventional hard combination is considered, in which CR users exchange only one bit of information regarding whether their observed energy value is above a certain threshold. In this paper, soft combination is investigated, in which accurate energy values observed by different CR users are combined to make a better decision. Existing spectrum sensing techniques can be divided into three types: energy detection, matched filter detection, and cyclostationary detection. We only consider energy detection for spectrum sensing in this paper. However, use of energy detector in a single antenna CR results in poor detection performance at low SNR region, thereby causing interference to the PU signal. We will show that cooperative frequency spectrum sensing in OFDM equipped with multiples antennas and square-law-combining (SLC) based energy detector in cognitive radio sensor networks scheme offer potential improvement in detection performance.

OFDM and MIMO technologys have been introduced in LTE and B3G, because OFDM and MIMO technologys are optimum from a capacity point of view. OFDM has been proposed as the best physical layer candidate for a CR system since it allows easy generation of spectrally shaped signal waveform that can fit into discontinuous and arbitrary sized spectrum segments. Hence, in our paper, we consider the performance of OFDM based CR sensor networks equiped with multiple antennas to receive the signal from primary user and uses SLC based energy detector to detect the presence of Pu.

II. OFDM System Model

In this section, we derive the cooperative spectrum detection probabilities of OFDM based MIMO cognitive radio sensor networks using energy detector to detect the presence of PU in a Rayleigh fading channel. We assume that the number of OFDM based MIMO detectors are D in sensor networks and the number of antennas of every detector are M . We consider PU transmitting OFDM signal with Q-subcarriers on a bandwidth W. The transmission parameters, such as symbol period, carrier frequency and sub-carrier spacing of PU-OFDM signal are defined as T_i, f_i and $(\Delta f)_i = 1/T_i$, respectively. The CR-OFDM system consists of K number of sub-carriers with symbol period T_s, carrier frequency f_s, and bandwidth B . In the following, we assume $f_s = f_i$ and derive the detection probabilities of PU signal on CR receiver with multiple antennas. In OFDM transmission system, the symbols of user are passed though Q-point IDFT block and cyclic prefix (CP) is added for eliminating inter-channel-interference (ICI) that brought about by multipath propagation. The resting signal is up-converted to carrier frequency (f_i) and then transmitted through wireless channel. The hth transmitted PU-OFDM symbol is given by

$$x(t-hT_i) = \sum_{i=0}^{Q-1} d_{h,i} \exp[j2\pi(t-hT_i)\frac{i+f_i}{T_i}] \tag{1}$$

Where, $d_{h,i}$ is PU symbol modulated on ith sub-carrier, generating h th PU-OFDM symbol.

III. COOPERATIVE SPECTRUM SENSING MODEL IN OFDM BASED MIMO COGNITIVE RADIO SENSOR NETWORKS

The received signal on CR is down converted, sampled at $T_d = T_S/K$ and passed through K-point DFT system. We consider the nth CR-OFDM symbol to fall within the span of PU signal's hth symbol. In detection of the nth OFDM symbol, the contribution of PU signal in a frequency selective fading channel at the down converter output of the receiver is given by

$$s(t-nT_s) = \exp[j2\pi f_s(t-nT_s)]\sum_{m=0}^{h-1} g_m x(t-hT_i-mT_s)$$
$$nT_s \le t < (n+1)T_s \tag{2}$$

where , g_m are coefficients of frequency selective fading channel. From (1) and (2) we can derive

$$\begin{aligned} s(t-nT_s) &= \sum_{m=0}^{h-1} g_m \sum_{i=0}^{Q-1} d_{h,i} \exp\left\{ j\frac{2\pi}{T_i}[i(t-hT_i-mT_s)+f_i(t-hT_i-mT_s)-f_s(t-nT_s)] \right\} \\ &= \sum_{i=0}^{Q-1} d_{h,i} H_i \exp[j\frac{2\pi i(t-hT_i)}{T_i} + j2\pi f_i(t-hT_i) - j2\pi f_s(t-nT_s)] \end{aligned} \tag{3}$$

where H_i is given by

$$H_i = \sum_{m=0}^{h-1} g_m \exp[-j2\pi m(f_i T_s + i\frac{T_s}{T_i})] \tag{4}$$

the resulting signal is then sampled at every T_d second, and the corresponding sampled signal is given as

$$s_p = \sum_{i=0}^{Q-1} d_{h,i} H_i \exp\left\{ j2\pi[\frac{pT_s}{K}(\frac{i}{T_i}+f_i-f_s)+(-hf_iT_i+nT_sf_s)] \right\} \tag{5}$$

the discrete time signal { s_p } is passed through a K-point DFT, which provides the signal component on z th sub-carrier as follows

$$s_z(n) = \sum_{z=0}^{K-1} s_p \exp\left\{ j\frac{2\pi pz}{K} \right\} \tag{6}$$

The received signal at the post of CR sensor DFT operation can be written as

$$R_z(n) = s_z(n) + N_z(n) \tag{7}$$

where $N_z(n)$ is DFT of complex noise sequence with variance σ_w^2 . The primary problem is to determine the presence (Hypothesis H_1) or absence (Hypothesis H_0) of PU signal. Assumption as above, received signal is denoted as

$$R_z(n) = \begin{cases} s_z(n) + N_z(n) & H_1 \\ N_z(n) & H_0 \end{cases} \quad n = 1,...,N \tag{8}$$

The energy detector forms the decision statistics (E_z) collecting N samples from the output of DFT block corresponding to zth sub-carrier. We compared E_z with threshold η and calculated for a given probability of false alarm (P_f) to detect the presence of PU signal. The decision making block marks the sub-carrier as unused when the decision statistics is less than threshold η value. This procedure is repeated for all the K sub-carriers and subsequently, the number of sub-carriers free for use by CR is determined. Under H_0, the normalized decision statistics is given as

$$\begin{aligned} E_z &= \frac{2}{\sigma_w^2}\sum_{n=1}^{N}\left|N_z(n)\right|^2 \\ &= \frac{2}{\sigma_w^2}\sum_{n=1}^{N}(\left|N_{zr}(n)\right|^2 + \left|N_{zi}(n)\right|^2) \end{aligned} \tag{9}$$

where, $N_{zr}(n)$ and $N_{zi}(n)$ are real and imaginary parts of $N_z(n)$ and they are zero mean gaussian random variable with variance $2/\sigma_w^2$. Thus, E_z under H_0, can be viewed as the sum of square of the 2N standard Gaussian i.i.d random variable with zero mean and unit variance. Hence, E_z follows a central chi-square distribution with 2N degree of freedom. The P_f is given as [10]

$$P_f = \frac{\Gamma(N, \eta/2)}{\Gamma(N)} \tag{10}$$

where, $\Gamma(.,.)$ is the incomplete gamma function, η is the threshold with which the decision statistics is compared to detect the presence of PU signal. Under H_1 , the decision statistics E_z is give as (11)

$$E_z = \frac{2}{\sigma_w^2} \sum_{n=1}^{N} \left| s_z(n) + N_z(n) \right|^2 \tag{11}$$

We can derive P_d from (11)

$$P_d = \int_{\eta}^{\infty} P_{E_z/H_1}(E_z) dE_z \tag{12}$$

From (8) we can derive the received signal under the presence (Hypothesis H_1) or absence (Hypothesis H_0) of PU signal at the ξth antenna as (13)

$$R_z^{\xi}(n) = \begin{cases} s_z^{\xi}(n) + N_z^{\xi}(n) & H_1 \quad n = 1, ..., N \\ N_z^{\xi}(n) & H_0 \quad \xi = 1, ..., M \end{cases} \tag{13}$$

From (8) and (13), we can derive the received signal of zth OFDM symbol in whole cognitive radio sensor networks. The normalized decision statistics for Square Law Combining (SLC) scheme is equal to the sum of the energy of all the received antennas which can be written as

$$E_z = \frac{2}{\sigma_w^2} \sum_{\xi=1}^{M} \sum_{n=1}^{N} \left| s_z^{\xi}(n) + N_z^{\xi}(n) \right|^2 \tag{14}$$

under H_0 and M antennas,

$$E_z = \frac{2}{\sigma_w^2} \sum_{\xi=1}^{M} \sum_{n=1}^{N} \left| N_z^{\xi}(n) \right|^2 \tag{15}$$

under H_1 and M antennas,

$$\begin{aligned} E_{zM} = & \frac{2}{\sigma_w^2} \sum_{n=1}^{N} \left| s_z^1(n) + N_z^1(n) \right|^2 + ... \\ & + \frac{2}{\sigma_w^2} \sum_{n=1}^{N} \left| s_z^M(n) + N_z^M(n) \right|^2 \end{aligned} \tag{16}$$

From (11) , (15), we can derive P_f as (17) under the condition of M antennas.

$$P_f = \frac{\Gamma(MN, \eta/2)}{\Gamma(MN)} \tag{17}$$

From (12) , (16), we can derive P_d as (18) under the condition of M antennas.

$$P_d = \int_{\eta}^{\infty} P_{E_{zM}/H_1}(E_{zM}) dE_{zM} \tag{18}$$

From above computing, we derived the value of P_f , P_d under the conditions that sensor networks have D sensor and every sensor has been equipped with M antennas. Now, we will derive P_f , P_d of whole cognitive radio sensor networks. Since value of P_f , P_d is related to other sensor estimation in Cooperative spectrum sensing , we use OR merge algorithm to derive P_f , P_d of whole cognitive radio sensor networks.

$$p_f = 1 - \prod_{i=1}^{D} (1 - k_i P_{f,i}) \tag{19}$$

$$p_d = 1 - \prod_{i=1}^{D} (1 - k_i P_{d,i}) \tag{20}$$

Where, k_i is merge decision correct factor (MDCF) of the ith sensor and $P_{f,i}$, $P_{d,i}$ are the probability of false alarm and the probability of detection of ith sensor.

IV. SIMULATION RESULTS

In our simulation, we consider the cooperative spectrum sensing in OFDM based on MIMO cognitive radio sensor networks consisting of 10×10=100 sensors and the PU-OFDM system consisting of Q=256 sub-carriers with symbol period $T_i = 26.6\mu s$. Subsequently, we consider CR receiver with $K = 128$ sub-carriers of symbol period $T_s = 26.6\mu s$. In our simulation, we consider carrier frequency $f_s = f_i = 2.819$ GHz. To show the detection performance of MIMO cognitive radio, we use complementary receiver operating characteristic (ROC) function.

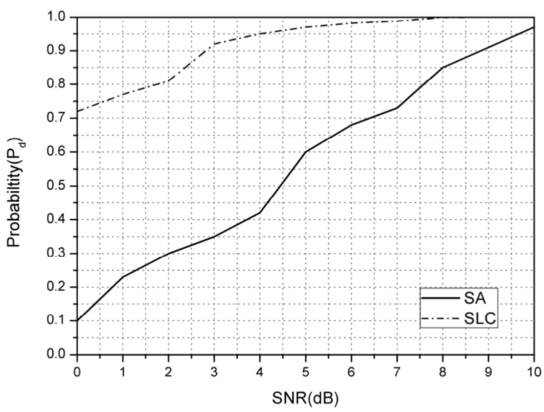

Figure 1. Probability of detection versus SNR for different diversity schemes based energy detector

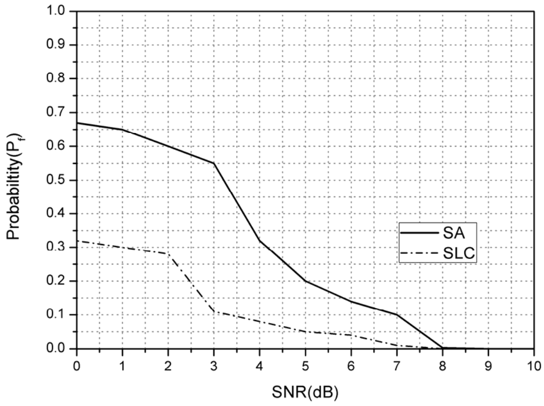

Figure 2. Probability of false alarm versus SNR for different diversity schemes based energy detector

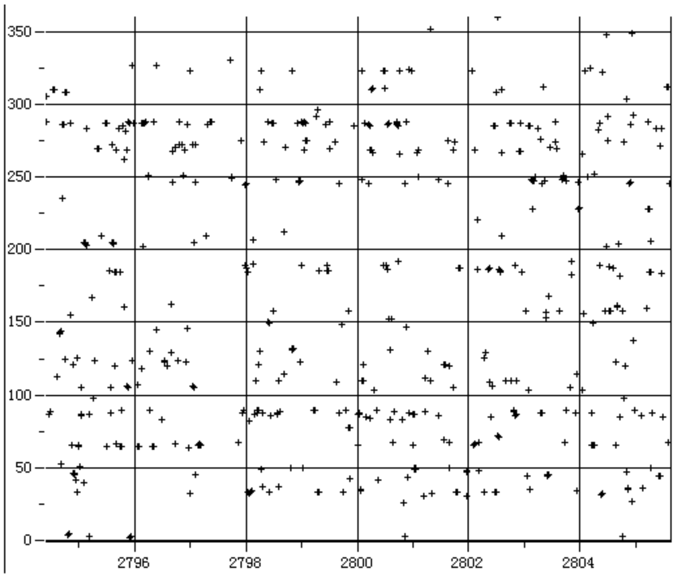

Figure 3. Probability of detection signals from 2794KHz to 2809KHz

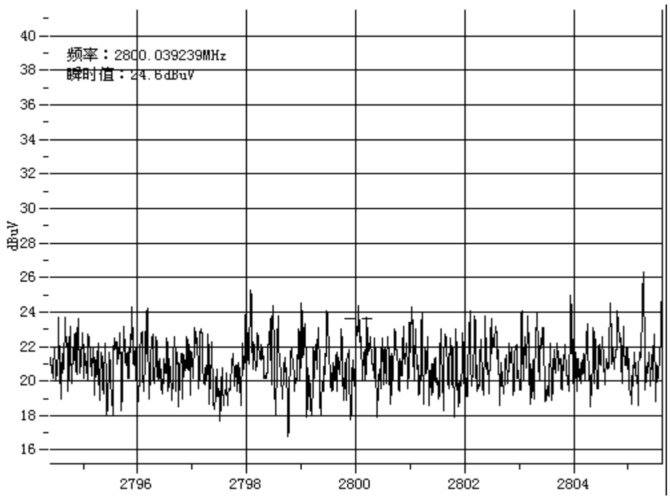

Figure 4. The level of frequency spectrum from 2794KHz to 2809KHz schemes based energy detector

We also did some practial experiments with some frequency spectrum monitor equipments. Fig.3 and Fig.4 shows the frequency spectrum utilization from 2794KHz to 2809KHz. From Fig.1 to Fig. 4, we can acquire results that our approach is more impressive than tradition in low SNR region.

V. CONCLUSION

In this paper, we considered networks level spectral sensing in OFDM based MIMO cognitive radio sensing networks. The SLC and cooperative spectrum sensing (CSS) provides high detection probabilities. We can see from Fig. 2 –Fig.5 that the SLC and CSS can provides higher detection probabilities at low to moderate SNRs.

REFERENCES

[1] M. A. McHenry, ‘’NSF spectrum occupancy measurements project summary,” Shared Spectrum Company, Vienna, VA, Tech. Rep., August 2005. [Online]. Available: http://www.sharedspectrum.com/section=measurements.

[2] FCC, “Spectrum Policy Task Force Report,” ET Docket No. 02-135, Nov. 2002

[3] J. Mitola et al., “Cognitive radio: making software radios more personal personal,” IEEE Pers. Commun., vol 6, no. 4, pp. 13-18, Aug. 1999

[4] S. Haykin, , “Cognitive radio: Brain-empowered wireless communications,” IEEE Journal Selected Areas in Commun., vol. 23, no. 2, pp. 201-220, Feb. 2005.

[5] D. Cabric, S. M. Mishra, D. Willkomm, R. W. Brodersen, and A. Wolisz, “A cognitive radio approach for usage of virtual unlicensed spectrum,” in Proc. 14th IST Mobile and Wireless Commun. Summit, June 2005.

[6] A. Sahai, N. Hoven, and R.Tandra, “Some fundamental limits in cognitive radio,” in Proc. Allerton Conf. on Commun., Control and Computing, Oct. 2004.

[7] G. Ganesan and Y. Li, “Agility improvement through cooperative diversity in cognitive radio,” in Proc. Global Telecommun. Conf., Nov. 2005, vol. 5, pp. 2505-2509.

[8] G. Ganesan and Y. Li, “Cooperative spectrum sensing in cognitive networks,” in Proc. IEEE Int. Symp. On New Frontiers in Dynamic spectrum Access Networks, Nov. 2005, pp. 137-143

[9] A. Ghasemi and E. S. Sousa, “Collaborative spectrum sensing for opportunistic access in fading environments,” in Proc. IEEE Int. Symp. On New Frontiers in Dynamic Spectrum Access Networks, Nov. 2005, pp.131-136.

[10] D. Cabric, S. M. Mishra, and R. W. Brodersen, “Implementation issues in spectrum sensing for cognitive radios,” in Proc. Asilomar Conf. on Signals, Systems, and Computers. Nov. 2004, vol. 1. pp. 772-776.