Out-of-band Cooperative Spectrum Sensing in Cognitive Radio System of Multiple Spectrum Bands

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Abstract: - This paper proposes the scheme of the out-of-band cooperative spectrum sensing in the cognitive radio (CR) base station to be operated by the multiple spectrum bands. And it suggests signal detection results for the ATSC TV signal as an incumbent signal, and derives signal detection probability and false-alarm probability for the out-of-band cooperative spectrum sensing in the frequency selective Rayleigh fading channel. Numerical results demonstrate that sensing performance for the incumbent signal is improved by the out-of-band cooperative spectrum sensing in case the power strengths of the incumbent signal to be measured by the CR users of the multiple channels are almost similar.

Key-Words: - Matched Filter Correlation, Signal Detection, Spectrum Sensing, Cognitive Radio

1. Introduction
The main object of the spectrum sensing can classify as two kinds of types in the CR system. The first object is that CR user acquires the communication channel, and the second object is to confirm the appearance of the incumbent user about the corresponding channel that the CR user utilizes.

In this paper, we propose the efficient out-of-band cooperative sensing method in the sensing process confirming the appearance of the incumbent user in the channel being used by the CR user.

The conventional papers suggest the cooperative sensing technique using the multiple CR users of one frequency channel and show the detection performance to be improved by the cooperative sensing [3][4]. In this paper, we propose the method that the all CR users of the multiple CR channels perform the cooperative sensing during the quiet period (QP) when the base station operates the multiple CR channels. The conventional papers suggest the cooperative sensing techniques to be performed by the multiple CR users of one CR channel, while this paper suggests the method that the CR users of the multiple CR channels perform the cooperative sensing at the quiet period (QP) to be designated to the multiple CR channels when the base station operates the multiple CR channels.

2. Signal Detection Analysis of ATSC Digital TV Signal
Currently, the standardization of the CR system such as WRAN and UCoMs has been performed using the conventional TV band. Thus, in this paper, we consider the spectrum sensing model to set incumbent signal as the ATSC digital TV signal.

The structure of digital TV signal is as follows. The data frame of digital TV signal is consisted of 313 segments, and one segment is consisted of the four data segment synchronization symbols and the 828 Reed Solomon (RS) encoded symbols. And the data segment sync symbol pattern is represented as “1001” of a binary level. The data frame of the ATSC TV signal is comprised of 24.2ms of 313 segments. The first segment of 313 segments is the field sync symbol pattern of 832 symbols, and it is repeated every frame. The content of the 832 symbols is comprised of the 511 PN code sequence and the 63 PN code sequence to be repeated with 3 times [5].

From the structure of the field sync symbol pattern of 832 symbols, the detection method can be composed of three kinds of methods using the data segment sync symbol pattern, using the PN511 code sequence, and using the PN63 code sequence.

In this paper, the matched filter (MF) correlator using the PN511 code sequence is comprised of the signal detector structure for the ATSC TV signal detection. Moreover, when the detection performance of the incumbent signal in the out-of-band cooperation sensing is analyzed, the signal detection result of the noncoherent MF correlator structure is analyzed by considering the multi-channel CR system and the frequency selective Rayleigh fading channel with the most inferior case.

When the channel gain the f-th frequency channel is given as $\alpha_f$, the output of noncoherent MF correlator, $Z_i$, in the frequency-selective Rayleigh fading channel is given by

$$Z_i \sim \left| N_s E_s \sum_{\gamma=1}^\infty \alpha_i^j R^2(\lambda_j) + NN_0, \quad H_0, i = 1, 2, \ldots, I \right|$$

where $N$ and $E_s$ are coherent integration length and symbol energy respectively. And then $\alpha_i$ and
\( \lambda_j \) are the gain of the \( j \)-th path and the path difference between the \( j \)-th path and \( i \)-th path, and \( N_s \) and \( N_c \) are the number of multi-paths and interference noise spectral density, respectively. Also \( R(\lambda_j) \) for the time-limited filter is given by

\[
R(\lambda_j) = \begin{cases} \frac{1}{\lambda_j T_s} & \text{if } |\lambda_j| T_s < T, \\ 0 & \text{otherwise} \end{cases}
\]

where \( \lambda_j = |\tau_i - \tau_j| \), and \( \tau_i \) and \( \tau_j \) are the path delay of the \( i \)-th path and the \( j \)-th path, respectively.

3. Out-of-band Cooperative Spectrum Sensing

The conventional papers suggest the cooperative sensing technique using the multiple CR users of one frequency channel and show its detection performance \([3][4]\). In this paper, we propose the method that the all CR users of the multiple CR channels perform the cooperative sensing during the quiet period (QP) when the base station operates the multiple CR channels.

Fig. 1. Superframe structure of out-of-band cooperative spectrum sensing in case of multi-channel CR system.

Fig. 1 is the superframe structure for the out-of-band cooperative spectrum sensing in the multiple access schemes such as TDMA, CDMA, and OFDMA. The conventional research proposes the in-band cooperative spectrum sensing using the multiple CR users of one frequency channel and evaluates its sensing performance.

In Fig. 1, the timing synchronization in the downlink has to be made for the \( F \) frequency channels so that the out-of-band cooperative spectrum sensing can be possible. And all CR users within the base station or access point find out the information about the location of the quiet period (QP) of each frequency channel. From the prior condition, the centralized cooperation sensing method has to inform the location of the quiet period of the CR frequency channel using the superframe header in the AP or the BS per a superframe.

Moreover, the receiver structure of the CR terminal is altogether equipped with the signal detector for spectrum sensing and the receiver for a communication so that the out of band cooperation sensing can be performed. As a example, in order to perform the cooperative sensing for channel \( F \) being shown in Fig. 1, the receiver of CR terminal for channel 1, 2, and 3 become to need the two RF paths that perform the cooperative spectrum sensing for the channel \( F \) and communicate with the BS. In Fig. 1, \( T_s \) is the sensing period of the CR channel, \( T_i \) and \( T_q \) are the channel switch time and the quiet period, respectively.

Fig. 2 shows the execution process about the centralized out-of-band cooperative spectrum sensing. In the flowchart of the out-of-band cooperative spectrum sensing, at first, the BS or AP collects the multiple CR channels and then it performs to synchronize for all CR channels on the downlink. Then the BS or AP determines the QP (quiet period) location of each frequency channel and transmits the QP location information of all CR channels. After receiving the QP location information of all CR channels, the out-of-band spectrum sensing is performed.


The signal detection probability at the spectrum sensing is the probability detecting the incumbent signal and the false alarm probability is the probability of determining as an error that the incumbent signal exists in the situation which the incumbent signal doesn’t exist.

In this paper, the spectrum sensing structure is composed of the noncoherent matched filter (MF) correlator using the PN511 code sequence. Therefore, the output of the PN511 MF correlator is compared with a threshold, and then the presence of the incumbent signal is detected in the situation where the code synchronization of the PN511 code sequence is performed.
From the output of the PN511 MF correlator, the non-coherent MF correlator means $V_{f_i}$, $i = 1, 2, ..., I$ corresponding to $H_i, i = 1, 2, ..., I$ in the case of $H_1$ hypothesis is given by [7]

$$V_{f_i} = N^2 E_x \left[ \alpha_f \right] \sum_{j=1}^{N_f} E_x \left[ \alpha_f \right] R^2 (\lambda_f)$$

$$+ NN_0, i = 1, 2, ..., I$$

(3)

where $\alpha_f$ is the channel gain of the $f$-th frequency channel, $R(\lambda_f) = \left| H(f) \right|^2 \cos(2\pi \lambda_f) df$, and then $N$ and $E_x$ are the coherent integration length and PN code symbol energy respectively. $N_p$ and $\alpha_f$ are the number of multi-paths and the $j$-th path amplitude respectively, and $\lambda_f$ is the timing error between the $j$-th path and code sequence of the PN code symbol sequence corresponding to $H_1$ cell. Using (3), the probability density function of $\eta(= Z_f)$ under $H_1$ hypothesis is given by

$$f_\eta(\eta|H_1) = \frac{1}{V_{f_i}} e^{\frac{\eta}{V_{f_i}}} \text{, } i = 1, 2, ..., I$$

(4)

Under the frequency-selective fading channel of the $f$-th frequency channel, the signal detection probabilities of $H_i, i = 1, 2, ..., I$ cells are given by

$$P_{D_i}^f = \int_\eta f_\eta(\eta|H_i) d\eta, \text{ } i = 1, 2, ..., I$$

(5)

$$= e^{-\eta/V_{f_i}}$$

, where $\eta$ is the detection threshold.

Then, in this paper, because the transmission quiet period (QP) for the spectrum sensing of the operating channel is identical with one data frame, the signal detection probability, $P_{D_i}^f$ for the multiple $H_1$ cells is represented by

$$P_{D_i} = \prod_{j=1}^{I} \left( 1 - P_{D_i}^f \right)$$

(6)

Also, the false alarm probability is given by

$$P_{F_i}^f = \int_\eta f_\eta(\eta|H_0) d\eta$$

(7)

$$= e^{\eta/V_{f_i}}$$

, where $V_N = NN_0$ and the probability density function of $\eta(= Z_f)$ under $H_0$ hypothesis is given by

$$f_\eta(\eta|H_0) = \frac{1}{V_N} e^{\frac{-\eta}{V_N}}$$

(8)

When the number of CR users to be assigned to each frequency channel is given as $U_f, f = 1, 2, ..., N_f$, in case that the $N_f$ frequency channels in the multi-channel CR system are used, the signal detection probability and false alarm probability for the out-of-band cooperative spectrum sensing are represented by

$$P_{D_i} = 1 - \prod_{j=1}^{N_f} \left( 1 - P_{D_i}^f \right)$$

(9)

$$P_{F_i} = 1 - \prod_{j=1}^{N_f} \left( 1 - P_{F_i}^f \right)$$

(10)

5. Numerical Results

In this paper, the performance of the out-of-band cooperative spectrum sensing was analyzed in the system environment in which the CR base station runs the multi-frequency channel about the IEEE802.22 WRAN channel [8].

The multipath profile such as profile A and profile B of the IEEE802.22 WRAN channel were reconstructed in consideration of the PN chip duration of 93ns, that is the code symbol duration of the ATSC TV signal. If the three paths in which the signal strength is superior are selected in each multipath profile, in case of the multipath profile A, it is composed of multi-paths having the signal strength including 0.8123, 0.1621, and 0.257. In case of the multipath profile B, it is composed of paths having the signal strength including 0.1731, 0.6893, and 0.1375. Here, the sum of the path powers in both the profile A and profile B is normalized with 1.

In this paper, using (9) and (10), the signal detection probability and false alarm probability for the out-of-band cooperative spectrum sensing are derived.

![ROC of cooperative out-of-band cooperative spectrum sensing in WRAN channel A.](image)

Fig. 3. ROC of cooperative out-of-band cooperative spectrum sensing in WRAN channel A.

Fig. 3 shows ROC of the out-of-band cooperative spectrum sensing using CR users communicating with the mutually different the frequency channel at the WRAN channel environments. In Fig. 3, $N_c$ is the number of the communicating frequency channels and $N_u$ is the number of CR users per each frequency channel. When $N_c = 1$, this case is that the out-of-band cooperative spectrum sensing is not performed, otherwise, when $N_c$ is more than 2, the
out-of-band cooperative spectrum sensing is performed using the multiple operating channels. In this case, the sensing performance is improved in proportion to the number of channels being applied to the cooperative spectrum sensing.

![Fig. 4. Detection probability of incumbent signal vs. $E_s/N_0$ according to the change of false alarm probability.](image)

Fig. 4 shows detection probability of incumbent signal to applying the out-of-band cooperative spectrum sensing using the CR users of the multiple CR channels, when the false alarm probabilities are given as 10% and 1% respectively. In Fig. 4, when the false alarm probability is less than 1%, in the case of the high $E_s/N_0$ compared to low $E_s/N_0$, the sensing performance of the out-of-band cooperative spectrum sensing is improved remarkably.

Fig. 5 shows detection probability of incumbent signal for the out-of-band cooperative spectrum sensing when the false alarm probabilities are 10% and the received powers to be measured by the CR users of the two channels are different. Here, $N_c$ is the number of the CR channels and $N_u$ is the number of CR users to perform the measurement of the incumbent signal per the CR channel. In Fig. 5, when the CR users of the two channels measures the power of the incumbent signal, the sensing performance is improved in case the difference of received powers to be measured by the CR users of the two channels is 3dB or less, but it is degraded in case the difference of the two received powers is 6dB or more. Therefore the out-of-band cooperative spectrum sensing must be performed using both the difference of power strength and the sensing result to be collected by the CR terminal.

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**References**


