Improved MCAS based spectrum sensing with multiple antennas

Shusuke Narieda¹, a) and Hiroshi Naruse¹

¹ Graduate School of Eng., Mie Univ., 1577 Karimamachi yach o, Tsu-shi, Mie, 514–8507, Japan
a) narieda@pa.info.mie-u.ac.jp

Abstract: This letter presents improved maximum cyclic autocorrelation selection (MCAS) based spectrum sensing techniques with multiple antennas. The improved MCAS based spectrum sensing employs two types of statistic; one includes an information of target signals and another one is for the comparison with the former one. These statistics are computed from a cyclic autocorrelation function (CAF) at only one cyclic frequency. In this letter, we attempt to enhance the performance of signal detection by selecting a receive antenna element with a minimum statistic for the comparison. The presented results are compared with some conventional results. Numerical examples are shown to validate the effectiveness of the presented technique and the performance of the presented technique is superior to the conventional technique.

Keywords: spectrum sensing, improved MCAS, multiple antennas

Classification: Wireless Communication Technologies

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1 Introduction

In spectrum sharing systems, such as Citizens Broadband Radio Service (CBRS) which is begin considered by Federal Communications Commision (FCC) in the US [1], spectrum sensing techniques are employed to learn the radio environment. In CBRS, the sensing dedicated nodes and generalized authorized access (GAA) users play the role of the spectrum sensing. Therefore, low computationally and high accuracy spectrum sensing techniques have been expected. Cyclostationary detection based spectrum sensing is robust to the effect of fading or interferences and can classify the modulation schemes of radio communication signals [2, 3]. Further, multiple antenna techniques can enhance the performance of signal detection. Some cyclostationary detection based spectrum sensing techniques with multiple antenna techniques have been presented [4, 5, 6]. In this letter, aiming for further performance enhancement maintaining the low computational complexity, we present spectrum sensing techniques with multiple antennas based on the improved maximum cyclic autocorrelation selection (MCAS) technique [3] which has low computational complexity.

2 Preliminary notions

2.1 System model

We assume that one secondary user (SU), such as the GAA user, attempts to sense a primary user (PU) communication, i.e., this is general spectrum sensing problems which can be considered as a binary hypothesis testing problem. Let $\mathcal{H}_1$ and $\mathcal{H}_0$ denote hypotheses which represent the PU that are active and inactive respectively. These can be expressed as

$$\begin{align*}
\mathcal{H}_1 : r_i(n) &= h_i x(n) + v_i(n) \\
\mathcal{H}_0 : r_i(n) &= v_i(n)
\end{align*}$$

where $r_i(n)$, $h_i$, $x(n)$, $v_i(n)$ and $N_r$ are the received complex signals at the $i$th receive antenna, the complex channel gain between the transmitter and the $i$th receive antenna, the transmitted complex PU signal, and the additive white Gaussian noise (AWGN) at the $i$th receive antenna, i.e., $v_i(n) \sim CN(0, \sigma_i^2)$, $\forall i$ and the number of receive antennas, respectively. $x(n)$ and each $v_i(n)$, $\forall i$ are statistically independent with each other.

2.2 Improved MCAS

In cyclostationary detection based spectrum sensing, the cyclic autocorrelation function (CAF) of received signals is used for signal detection. The CAF of orthogonal

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frequency division multiplexing (OFDM) signals can be approximated to compute
the discrete and finite-time signals \( r_i(n) \) as

\[
\hat{R}_{ri,N}^{\alpha_i} (n) = \frac{1}{N} \sum_{m=-N+1}^{n} r_i(m) r_i^*(m + N \Delta t) e^{-2j\pi \alpha_i m \Delta t}, \quad i = 1, \ldots, N_r, \quad (2)
\]

where \( N, \Delta t, \hat{R}_{ri,N}^{\alpha_i} (n), N_{\text{FFT}} \) and \( (\cdot)^* \) are the number of samples, sampling period and the approximated CAF at cyclic frequency \( \alpha_i (\alpha_i = 1/N_{\text{OFDM}} \) where \( N_{\text{OFDM}} \) is
the number of samples for one OFDM symbol) computed by \( r_i(n) \), \( N \) samples, the
number of samples for data duration of OFDM symbol and complex conjugate,
respectively. We let \( T_\alpha \) and \( T_{\beta_k} \) denote statistics for signal detection, and these for
\( r_i(n) \), i.e., the single antenna case, can be written as [3]

\[
T_\alpha = \left| \hat{R}_{ri,N}^{\alpha_i} (n) \right| \quad (3)
\]

\[
T_{\beta_k} = \sqrt{\frac{N'}{N - N'}} \left| \hat{R}_{ri,N}^{\alpha_1} (n) - \hat{R}_{ri,N'}^{\alpha_1} (n - k N') \right|, \quad k = 0, \ldots, N_\beta - 1, \quad (4)
\]

where \( N' \) and \( N_\beta \) are the number of samples for \( T_{\beta_k} \) and an positive integer for
design of PFA, i.e., \( P_{FA} = 1/(1 + N_\beta) \) where \( P_{FA} \) is a target false alarm probability,
respectively. Note that \( T_{\alpha_1} \) is peak CAF, i.e., \( T_{\alpha_1} \) has an information whether the
target signals are included in \( r_i(n) \) or not, whereas \( T_{\beta_k} \) is non-peak CAF, i.e., \( T_{\beta_k} \)
are the statistics for the comparison with \( T_{\alpha_1} \). The improved MCAS executes signal
detection as follows,

\[
T_{\alpha_1} \overset{\mathcal{H}_1}{\geq} \max_k T_{\beta_k}, \quad k = 0, \ldots, N_\beta - 1. \quad (5)
\]

3 Presented technique

3.1 Improved MCAS based spectrum sensing with multiple antennas

In this subsection, we present the improved MCAS based spectrum sensing with
multiple antennas. First, statistics \( T_{\alpha_1}^{(N_k)} \) and \( T_{\beta_{k,\gamma}}^{(N_k)} \) for the multiple antennas case
which correspond to eqs. (3) and (4) are defined as follows,

\[
T_{\alpha_1}^{(N_k)} = \left| \frac{1}{N_k} \sum_{i=1}^{N_k} \hat{R}_{ri,N}^{\alpha_i} (n) \right| \quad (6)
\]

\[
T_{\beta_{k,\gamma}}^{(N_k)} = \sqrt{\frac{N'}{N_k N' - N'}} \left| \frac{1}{N_k} \sum_{i=1}^{N_k} \hat{R}_{ri,N}^{\alpha_i} (n) - \hat{R}_{ri,N'}^{\alpha_i} (n - k N') \right|, \quad k = 0, \ldots, N_\beta - 1, \quad (7)
\]

where \( N' \) and \( \gamma \) are the number of samples for \( \hat{R}_{ri,N'}^{\alpha_i} (n - k N') \) and an integer value which represents the receive antenna number, i.e., \( \gamma = 1, \ldots, N_k \), respectively.
Note that \( T_{\beta_{k,\gamma}}^{(N_k)} \) are obtained from the \( \hat{R}_{ri,N'}^{\alpha_i} (n) \) at all receive antennas and the
\( \hat{R}_{ri,N'}^{\alpha_i} (n - k N') \) from the \( \gamma \)th receive antenna. The presented technique executes signal
detection as follows,

\[
T_{\alpha_1}^{(N_k)} \overset{\mathcal{H}_1}{\geq} \max_k T_{\beta_{k,\gamma}}^{(N_k)}, \quad k = 0, \ldots, N_\beta - 1. \quad (8)
\]

As noted previous, although \( T_{\beta_{k,\gamma}}^{(N_k)} \) exist for only the comparison with \( T_{\alpha_1}^{(N_k)} \) in the
MCAS based spectrum sensing, we attempt to enhance the performance of signal
detection by choosing $\gamma$ which determines the computation of $T^{(N_k)}_{\beta,\gamma}$. Concretely, $\gamma$ is determined as follows,

$$\gamma = \arg \min_i |\hat{R}_{r_i,N}^n(n)|, \quad i = 1, \ldots, N_k. \tag{9}$$

Eq. (9) aims to reduce the variance of $T^{(N_k)}_{\beta,\gamma}$ computed from small $\hat{R}_{r_i,N'}^n((n-kN')s)$, i.e., $\hat{R}_{r_i,N'}^n((n-kN')s)$ are obtained from the minimum $\hat{R}_{r_i,N}^n(n)$. As a result, in $\mathcal{H}_1$, the performance enhancement can be expected because of the small $T^{(N_k)}_{\beta,\gamma}$ and eq. (8). However, in $\mathcal{H}_0$, the performance of false alarm probability may be deteriorated because of the selection. The effect of the selection for the computation of $T^{(N_k)}_{\beta,\gamma}$ on the performances of the presented technique is numerically shown in next section.

4 Numerical examples

We assume that the target signal is the OFDM signal where $N_{\text{FFT}}=256$, and the data symbols are modulated with quadrature phase shift keying and are conveyed by 192 subcarriers. The numbers of samples for cyclic prefix $N_{CP}$ ($N_{\text{OFDM}} = N_{\text{FFT}} + N_{CP}$) are chosen as $N_{\text{FFT}}/4 = 64$ and $N_{\text{FFT}}/8 = 32$, and the numbers of samples for signal detection $N$ are chosen as 5120 and 4608. Rayleigh fading channel is employed as a communication channel with no correlation between receive antennas, i.e., all $h_i, \forall i$ are modeled as stochastic variables with i. i. d. process which follow $CN(0, 1)$. The purpose of the employing the simple channel model is for the fundamental evaluation of the presented technique. In this section, the performance of three techniques is compared; the improved MCAS based technique (presented technique), the improved MCAS based technique without the selection for the computation of $T^{(N_k)}_{\beta,\gamma}$, i.e., fixed $\gamma$ ($\gamma = 1$) is used for signal detection and the conventional technique [6].

First, we show the performance of false alarm probability for different $N_k$ and $P_{\text{FA}}$. Table I shows the performance of false alarm probability. As shown in Table I, almost results of three techniques are not much deteriorated and it can be considered that the effect of the selection for the computation of $T^{(N_k)}_{\beta,\gamma}$ is small. However, the results of the presented technique for $N_k = 8$ and $P_{\text{FA}} = 0.05, 0.1$ are deteriorated in

| $N_k$ | technique | $P_{\text{FA}} = 0.01$ | $P_{\text{FA}} = 0.05$ | $P_{\text{FA}} = 0.1$ |
|-------|------------|-----------------|-----------------|-----------------|
| 2     | presented technique | $0.941 \times 10^{-2}$ | $0.502 \times 10^{-2}$ | $0.101 \times 10^{-1}$ |
|       | without selection   | $0.929 \times 10^{-2}$ | $0.499 \times 10^{-1}$ | $0.101 \times 10^{-1}$ |
|       | conventional technique | $0.914 \times 10^{-2}$ | $0.497 \times 10^{-1}$ | $0.100 \times 10^{-1}$ |
| 4     | presented technique | $0.929 \times 10^{-2}$ | $0.510 \times 10^{-1}$ | $0.105 \times 10^{-1}$ |
|       | without selection   | $0.926 \times 10^{-2}$ | $0.503 \times 10^{-1}$ | $0.100 \times 10^{-1}$ |
|       | conventional technique | $0.918 \times 10^{-2}$ | $0.499 \times 10^{-1}$ | $0.100 \times 10^{-1}$ |
| 8     | presented technique | $0.925 \times 10^{-2}$ | $0.540 \times 10^{-1}$ | $0.115 \times 10^{-1}$ |
|       | without selection   | $0.921 \times 10^{-2}$ | $0.501 \times 10^{-1}$ | $0.100 \times 10^{-1}$ |
|       | conventional technique | $0.923 \times 10^{-2}$ | $0.499 \times 10^{-1}$ | $0.100 \times 10^{-1}$ |
Fig. 1. Rayleigh fading channel case: performance of ROC curves for different SNR, $N_{CP} = N_{FFT}/4$, $N_R = 2$.

(a) SNR = -4 dB, $N_{CP} = N_{FFT}/4$, $N_R = 2$.

(b) SNR = -1 dB, $N_{CP} = N_{FFT}/8$, $N_R = 2$.

(c) SNR = -7.5 dB, $N_{CP} = N_{FFT}/4$, $N_R = 4$.

(d) SNR = -4 dB, $N_{CP} = N_{FFT}/8$, $N_R = 4$.

(e) SNR = -10 dB, $N_{CP} = N_{FFT}/4$, $N_R = 8$.

(f) SNR = -7 dB, $N_{CP} = N_{FFT}/8$, $N_R = 8$.

Next, we show the performance of receiver operating characteristic (ROC) curves for different average signal power to noise ratio (SNR) for all receive antennas. Note that different SNRs are employed for each result in Fig. 1 for the evaluation of the performance at that the signal detection probability is around 0.9. Fig. 1 shows the performance of ROC curves. As shown in Fig. 1, the performances of the presented technique are superior to those of other techniques. Comparing Table I and Fig. 1, it can be seen that the selection for the computation of $\beta_{NL,Y}$ can achieve the performance enhancement. This is also the same for the presented technique (Fig. 1(e)) where the performance of false alarm probability is deteriorated as shown comparison with the results of other techniques. Although it can be considered that the reason is to be effected by the selection, the discussion of the effect is shown in next results.
in Table I. It can be seen that the effect of the selection on the performance enhancement is greater than the effect of the selection on the performance deterioration. Furthermore, comparing $N_{cp} = N_{fft}/4$ case and $N_{cp} = N_{fft}/8$ case, it can be seen that the performances of the $N_{cp} = N_{fft}/8$ case are more enhanced than those of the $N_{cp} = N_{fft}/4$ case. Note that it is known that the performance of the cyclostationary detection for the OFDM signals deteriorates as $N_{cp}$ decreases [7].

Finally, we provide a consideration for the performance enhancement of the presented technique. The results shown in Table I and Fig. 1 indicate that the performances in $\mathcal{H}_1$ can be enhanced by the presented technique whereas the performances in $\mathcal{H}_0$ are not much deteriorated by the presented technique. We consider the reason as follows. In the finite duration of signal detection, statistical properties of the observed arrived target signals are not the same due to Rayleigh fading channel whereas the properties of observed AWGNs at all receive antennas are almost the same. Therefore, even if either receive antenna element is selected, $\hat{R}_{r_1,r_2,N_1}^t(n)$ in $\mathcal{H}_0$ is almost the same whereas $\hat{R}_{r_1,N_2}^t(n)$ in $\mathcal{H}_1$ is not almost the same. To verify this, we evaluate the performance of the presented technique in AWGN channel. Fig. 2 shows the performance of ROC curves in AWGN channel for different average SNR and $N_{cp}$. As shown in Fig. 2, the performances of three techniques are almost the same and the consideration shown in above is verified. From these, it can be seen that the presented technique is effective in the channel where the strength of the arrived signal at each receive antenna is different, e.g., Rayleigh fading channel.

5 Conclusion

This letter presented the improved MCAS based spectrum sensing with multiple antennas. We attempted to enhance the performance of signal detection by selecting a minimum statistic for the comparison. The presented results were compared with some conventional results. Numerical examples were shown to validate the effectiveness of the presented technique and the performance of the presented technique was superior to the conventional technique.

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