International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:11, 2014

Centralized Cooperative Spectrum Sensing with MIMO in the Reporting Network over $\kappa - \mu$ Fading Channel

S Hariharan, K Chaitanya, P Muthuchidambaranathan

Abstract—The IEEE 802.22 working group aims to drive the Digital Video Broadcasting-Terrestrial (DVB-T) bands for data communication to the rural area without interfering the TV broadcast. In this paper, we arrive at a closed-form expression for average detection probability of Fusion center (FC) with multiple antenna over the $\kappa - \mu$ fading channel model. We consider a centralized cooperative multiple antenna network for reporting. The DVB-T samples forwarded by the secondary user (SU) were combined using Maximum ratio combiner at FC, an energy detection is performed to make the decision. The fading effects of the channel degrades the detection probability of the FC, a generalized independent and identically distributed (IID) $\kappa - \mu$ and an additive white Gaussian noise (AWGN) channel is considered for reporting and sensing respectively. The proposed system performance is verified through simulation results.

Keywords—IEEE 802.22, Cooperative spectrum sensing, Multiple antenna, $\kappa - \mu$.

I. Introduction

COGNITIVE Radio (CR) is an emerging smart wireless communications technology that will be able to find and connect with any nearby open radio frequency spectrum(Spectrum Hole/White Space) to best serve the SU's [1]. IEEE 802.22 wireless Regional Area Network (WRAN) standard aims to utilize the DVB-T bands for data communication and the primary objective of the WRAN is to utilize the DVB-T spectrum efficiently when the spectrum is idle [2], [3]. To access the free spectrum the SU has to detect the existence of the primary user (PU), For that, SU has to sense the spectrum periodically. The challenge in sensing the spectrum is SU should minimize the interference to the Television broadcasting and efficiently sense the spectrum holes to get the required throughput and Quality of Service. The spectrum sensing techniques and performance analysis of different sensing schemes for IEEE 802.22 standard over fading channels is discussed in [4]–[9].

In order to minimize the interference to the PU and to improve the detection probability many sensing techniques were already being analyzed, the low complex and very basic sensing method is energy detection (ED) and it is well discussed in [10]. The disadvantage with ED is performance degrades at lower signal to noise ratio (SNR). The disruptive effects of the various scenarios such as multipath fading, shadowing and receiver uncertainty are overcome by cooperative spectrum sensing (CSS). The CSS utilize the spatial diversity and improves detection probability [11]–[14], the CSS analysis for WRAN system is discussed in [15]. For a fixed broadband wireless access applications the multiple antenna technologies has significant benefits [16]–[18], hence recent research shows much interest in using MIMO for cognitive radio systems. By deploying Multiple input Multiple output (MIMO) system in CR network to improve the sensing performance by using multiple antenna at SU to sense the PU signal and the results shows improvement in detection [19]–[22]. Thus by arraying multiple antenna at SU can bring a significant rise in the performance of the WRAN system. By introducing cooperative-MIMO system in the WRAN standard an effective detection can be achieved [23]–[27].

Most of rural place will have digital partition compared to the urban area. The IEEE 802.22 standard's foremost idea is towards better quality of service by considering the parameters: spectrum sensing, spectrum management, estimation of channel state information and transmit power control. In order to assure that the interference caused to the PU is below the tolerable level the SU's need to carry out spectrum sensing as an effective and active process. To make a accurate decision an excessive sensing and decision time is required over the effects of channel conditions, the recent studies in [28]–[30] discuss the interference models for cognitive WRAN. A number of distributions have been projected to illustrate the fading statistics of the wireless channel [31], [32] and the most common fading distributions are Rayleigh, Rice, Nakagami-m, Hoyt (Nakagami-q), and Weibull. The analytical performance of ED over different conventional fading channel were discussed in [33]. A generalized distributions were defined in [34], [36], for line of sight (LOS) $\kappa - \mu$ and for Non line of sight $\eta - \mu$. These distribution were described in terms of computable physical factor and also fit to experimental data than the conventional fading statistical distributions. The ED over $\kappa - \mu$ and extreme $\kappa - \mu$ fading is analyzed in [37].

In this paper, we consider a cooperative MIMO spectrum sensing scheme with an energy detector, multiple antennas at each SU and FC, the PU signal is DVB-T data. In rural area LOS propagation condition is possible so the reporting channels is consider as a $\kappa - \mu$ fading distribution and the sensing channel is an AWGN. Soft combining of received data samples at FC is performed using MRC. We derive a

S. Hariharan is with the Department of Electronics and Communication Engineering, National Institute of Technology, Tiruchirappalli, India. (e-mail: hariharan_su@yahoo.com).

K. Chaitanya and P. Muthuchidambaranathan are with Department of Electronics and Communication Engineering, National Institute of Technology, Tiruchirappalli, India.

closed form expression for average detection probability of FC over $\kappa - \mu$ in the reporting network with Multi User MIMO. Finally we analyze the detection performance of FC with various multiple antenna scenario and different κ and μ through simulation results. The rest of this paper is organized as follows. In Section II, the system model and channel under consideration is described. Section III evaluates the average detection probability analysis over $\kappa - \mu$ fading channel. While Section IV outlines the simulation results and Section V concludes the paper.

II. System Model

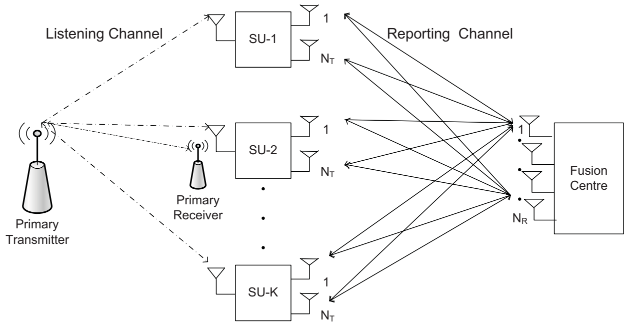

Fig. 1 Cooperative-MIMO reporting network

We consider a CR network of single PU, K-SU's with single antenna to sense the PU signal and N_T transmitting antenna to report to the FC and a FC equipped with N_R receiving antenna as shown in the Fig .1. It is assumed that the SU's do not have any information about the sensing channel and it is assumed to be a AWGN for analysis and the reporting channel experiencing IID $\kappa-\mu$ fading. The PU sample received at SU's is given by

$$R_k^{(n)} = \begin{cases} w_k^{(n)} & ;\mathcal{H}_0 \\ s_k^{(n)} + w_k^{(n)} & ;\mathcal{H}_1 \end{cases} \quad (1)$$

Where $s_k^{(n)} \sim \mathcal{CN}(0,1)$ is n^{th} PU sample received at k^{th} SU, $w_k^{(n)} \sim \mathcal{CN}(0,1)$ is the noise signal and assumed to be a complex Gaussian random variable, $1 \leq k \leq K$ and $1 \leq n \leq N$. The signal received at the FC is given by

$$R_{fc} = \begin{cases} \sum_{k=1}^{K}\sum_{n=1}^{N} W_k^{(n)} & ;\mathcal{H}_0 \\ \sum_{k=1}^{K}\sum_{n=1}^{N} H_k^{(n)} R_k^{(n)} + W_k^{(n)} & ;\mathcal{H}_1 \end{cases} \quad (2)$$

Where R_{fc} is a matrix of dimension $[N_R \times N]$, $W_k^{(n)}$ is $[N_R \times N]$ noise vector, $R_k^{(n)}$ is $[N_T \times 1]$ vector and the channel matrix $H_k^{(n)}$ is of dimension $[N_R \times N_T]$. The FC performs energy detection and the output of the detector is given by

$$Y = \sum_{i=1}^{N_R}\sum_{n=1}^{N} |R_{fc}(i,j)|^2 \quad (3)$$

Where Y is the observed energy value at FC. The sum of squares of N complex Gaussian random variable with zero mean and unit variance follows a central chi-square (χ^2) with $2N$ degrees of freedom under $\mathcal{H}_0$ and noncentral χ^2 with $2N$ degrees of freedom and $2N\gamma$ non centrality parameter under $\mathcal{H}_1$. Adding L IID noncentral χ^2 variate with $2N$ degrees of freedom and non-centrality parameter $2N\gamma$ will results in another noncentral χ^2 variate with $2NL$ degrees of freedom and non-centrality parameter $2NL\gamma$ where γ is the SNR [10], [18], [33], [38] and $L = N_R \times N_T$ is the number of diversity branches. If K independent SU with N_T transmitting antenna and the FC withN_R antennas, then the total diversity paths will be $K \times N_T \times N_R$ [17] therefore the degrees of freedom and non centrality parameter of the central and noncentral χ^2 variable will be given as $2NKL$ and $2NKL\gamma$ respectively. The PDF of Y can be written as

$$f_Y(y) = \begin{cases} \dfrac{(\frac{1}{2})^{(NKL)}}{\Gamma(NKL)} y^{NKL-1} e^{-\frac{y}{2}} & ;\mathcal{H}_0 \\ \frac{1}{2}(\frac{y}{2NKL\gamma})^{\frac{(NKL-1)}{2}} \exp\left(-\frac{y+2NKL\gamma}{2}\right) & \\ \quad \times I_{NKL-1}\left(\sqrt{2NKL\gamma y}\right) & ;\mathcal{H}_1 \end{cases} \quad (4)$$

where $\Gamma(.)$ is gamma function and $I_v(.)$ is the v^{th} order modified Bessel function of the first kind [38]–[40]. The probability of detection(P_d) and probability of false alarm (P_f) at the FC over an AWGN with cooperative MU-MIMO is given by [10], [14], [18], [24], [26], [33],

$$P_{\mathrm{f}} = \Pr(Y > \lambda|\mathcal{H}_0) = \frac{\gamma(NKL,\lambda)}{\Gamma(NKL)} \quad (5)$$

$$P_{\mathrm{d}} = \Pr(Y > \lambda|\mathcal{H}_1) = Q_{NKL}\left(\sqrt{2NKL\gamma}, \sqrt{\lambda}\right) \quad (6)$$

where λ is the decision threshold,$\gamma(.,.)$ denotes the incomplete gamma function and $Q_m(a,b)$ is the generalized Marcum Q-function [39], [40].

III. Analysis of Average Detection Probability

To obtain a closed form expression of an average detection probability averaging the conditional P_d in the AWGN case (6) over the output SNR distribution of the MRC over IID $\kappa - \mu$ fading distribution. The P_f will be the same for any fading channel condition as it is considered noise only criteria and independent of SNR. The pdf of output SNR (γ) of the MRC combiner with KL diversity paths over IID $\kappa - \mu$ fading channel is given by

$$f(\gamma) = \frac{KL\mu(1+\kappa)^{\frac{KL\mu+1}{2}}(\gamma)^{\frac{KL\mu-1}{2}}}{\kappa^{\frac{KL\mu-1}{2}}\exp(KL\mu\kappa)\overline{\gamma}^{\frac{KL\mu+1}{2}}} \times \exp\left(\frac{-KL\mu(1+\kappa)\gamma}{\overline{\gamma}}\right) \times I_{KL\mu-1}\left(2KL\mu\sqrt{\frac{\kappa(\kappa+1)\gamma}{\overline{\gamma}}}\right) \quad (7)$$

where κ is the ratio of the total power of the dominant components to that of scattered waves $\mu = \frac{E^2(\gamma)}{var(\gamma)} \times \frac{1+2\kappa}{(1+\kappa)^2}$ [34]–[37], γ is the instantaneous SNR and $\overline{\gamma}$ is the average SNR of each diversity paths. The average detection probability of FC over IID $\kappa - \mu$ fading channel, $\overline{P}_{d,\kappa-\mu}$ is given by

$$\overline{P}_{d,\kappa-\mu} = \int_0^\infty Q_{NKL}(\sqrt{2NKL\gamma}, \sqrt{\lambda}) f(\gamma) d\gamma \quad (8)$$

The integration in the above expression can be solved by using [[40],eqn. 33] while making the change of variables the $\overline{P}_{d,\kappa-\mu}$ is expressed as

$$\begin{aligned} \overline{P}_{d,\kappa-\mu} &= \frac{2A}{c}\left[\frac{c}{p^2}\right]^{NKL} \exp\left(\frac{c^2}{2p^2}\right) \\ &\times Q_{NKL}\left[\frac{ac}{p(\sqrt{p^2+a^2})}, \frac{bp}{\sqrt{p^2+a^2)}}\right] \quad (9) \\ A &= \frac{KL\mu(1+\kappa)^{\frac{KL\mu+1}{2}}(\gamma_{\kappa-\mu})^{\frac{KL\mu-1}{2}}}{\kappa^{\frac{KL\mu-1}{2}}\exp(KL\mu\kappa)\overline{\gamma}^{\frac{KL\mu+1}{2}}} \quad (10) \end{aligned}$$

where $c = 2KL\mu\sqrt{\frac{\kappa(\kappa+1)}{\overline{\gamma}}}$, $\frac{p^2}{2} = \frac{KL\mu(1+\kappa)}{\overline{\gamma}}$, $a = \sqrt{2KNL}$, $b = \sqrt{\lambda}$, $M = NKL$. By performing mathematical simplification the closed for expression of $\overline{P}_{d,\kappa-\mu}$ is

$$\begin{aligned} \overline{P}_{d,\kappa-\mu} &= \left[\frac{1+\kappa}{\kappa}\right]^{\frac{M}{2}} \times \frac{1}{(\overline{\gamma})^{\frac{M}{2}}}[\mu\kappa]^M \\ &\times Q_M\left[\frac{ac}{b(\sqrt{p^2+a^2})}, \frac{bp}{\sqrt{p^2+a^2)}}\right] \quad (11) \end{aligned}$$

IV. Simulation Results

The DVB-T signal of bandwidth 8 MHz operating in 8K mode with QPSK modulation and a code rate of 1/16 was considered. The sensing channel is assumed as an AWGN and the reporting channel experiences IID $\kappa-\mu$ fading. The sensing time of 15 ms and 500 realizations is considered for the Monte Carlo simulation. The threshold is obtained from (5) to meet the P_f of 0.01.

For study of the performance of different multiple antenna scenario in the reporting network we considered the antenna are uncorrelated and the FC has the reporting channel state information, In Fig.2 - Fig.7 we analyzed the performance of different multiple antenna scenario with 5 SU's for reporting with different κ and μ. The observation shows that the ED has better detection probability with multiple antenna when compared to the single antenna scenario. The effect of LOS component and multipath effect advantages also improves the detection performance. The detection probability of the energy detector improves at higher average SNR of the fading channel but with multiple antenna the ED has better performance at lower average SNR with MRC. Fig.(8) shows the performance of different multiple antenna scheme for $\kappa = 2$ and $\mu = 2$ and the observation shows increase in the number of antenna leads to better detection. The 2×2 and 1×4 scheme shows almost similar performance and the 4×4 has better performance than any other schemes. The 4×4 system achieves an interesting detection probability, according to [41] the minimum requirement for practical implementation of WRAN system the SU have to detect the DVB-T signal at -22.2 dB SNR with detection probability is about 90% and the minimum probability of false alarm is 0.1. In Fig.7 the detection probability of 90% is achieved about -25 dB. Thus by employing multiple antenna in the centralized cooperative reporting system we met the minimum requirement to implement WRAN system practically.

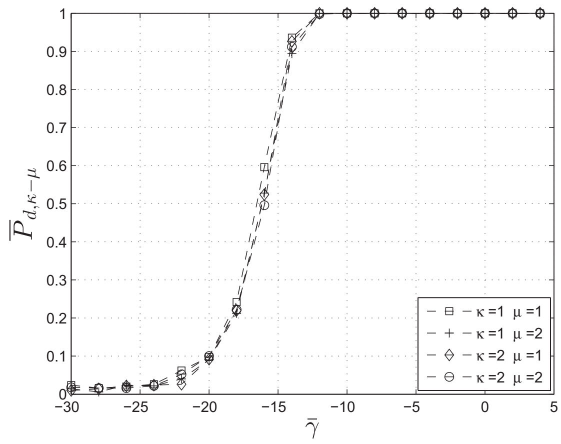

Fig. 2 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 1×1 system

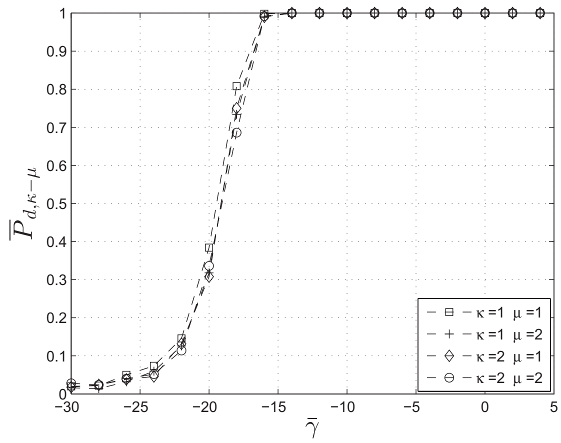

Fig. 3 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 1×2 system

V. Conclusion

In this paper we have discussed cooperative-MIMO spectrum sensing based reporting system for detecting DVB-T signal. The SU collaboratively shares the received DVB-T signal to the FC. We assume that the reporting channel has no bandwidth limitation and channel state information available at FC. We obtained the closed form expression for average detection probability of FC under multiple SU operating over IID $\kappa-\mu$ reporting channel with multiple antenna, MRC to perform data fusion and energy detection to make the final decision with an AWGN sensing channel. The $\kappa-\mu$ fading channel delivers a suitable channel characterization at FC, the

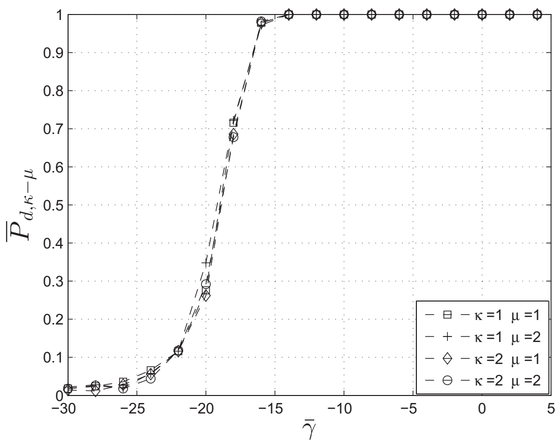

Fig. 4 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 2×1 system

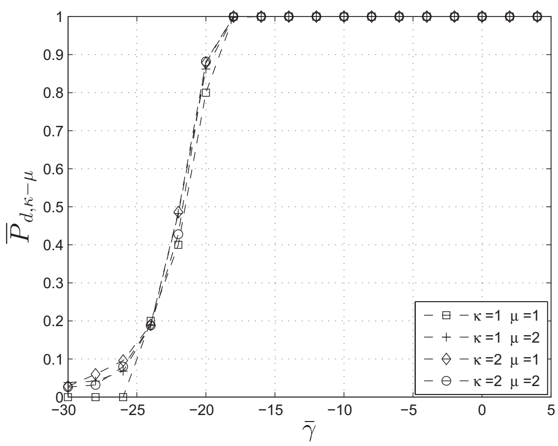

Fig. 5 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 2×2 system

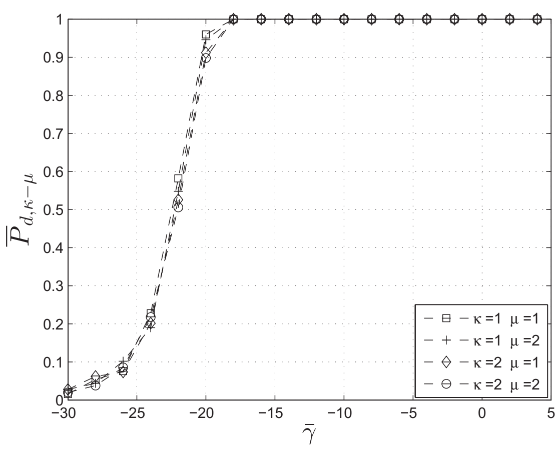

Fig. 6 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 1×4 system

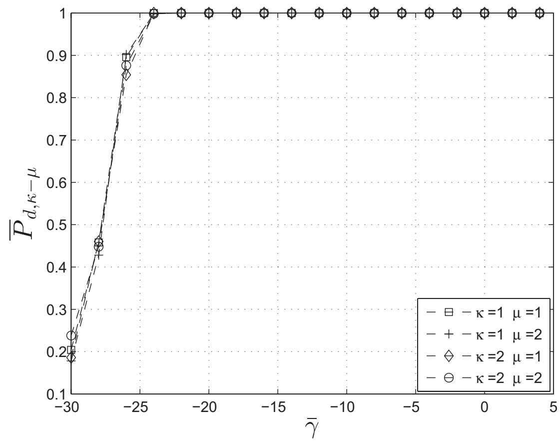

Fig. 7 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for 4×4 system

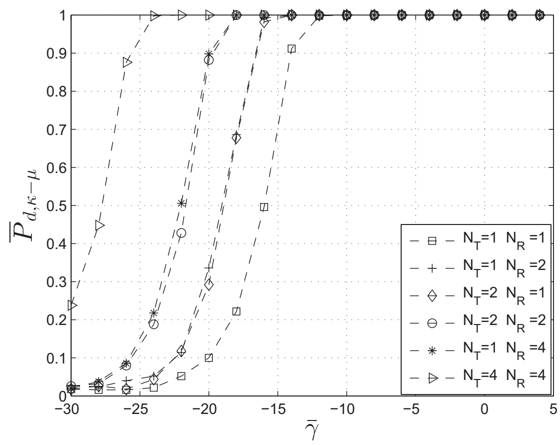

Fig. 8 $\overline{P}_{d,\kappa-\mu}$ vs Avg.SNR($\overline{\gamma}$) for $\kappa = 2$,$\mu = 2$

performance of the FC shows variations with small changes in the fading parameters and the multiple antenna scenario improves the performance of the energy detector at low SNR. The arrived average detection probability expression can be used to analyze the performance of conventional statistical channel models with multiple antenna at the reporting network. Since the 4×4 system with multiuser is more complex, either 2×2 or 1×4 can be utilized for practical deployment and can achieve same performance of 4×4 by optimizing the number of SU's.

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S Hariharan received his B.Eng. Degree in Electronics and Communication Engineering from Periyar University, Salem, Tamilnadu, India, in 2004, and the M.Eng. Degree in Communication Systems from Anna University, Chennai, India, in 2006. Currently he is pursuing his Ph.D. in cooperative communication networks in the Department of Electronics and Communication Engineering, National Institute of Technology (NIT), Tiruchirappalli, India. He is a recipient of Canadian Commonwealth Scholarship Award-2011 for Graduate Student Exchange Program in the Department of Electrical and Computer Engineering, University of Saskatchewan, Saskatoon, SK, Canada. His research interests include cooperative spectrum sensing, statistical signal processing, orthogonal frequency division multiplexing (OFDM), multiple-input and multiple-output (MIMO) systems and vector quantization.

K Chaitanya received his B.Tech. Degree in Electronics and Communication Engineering from Narayana Engineering College, Nellore, Andhrapradesh, India, in 2013. Currently he is pursuing his M.Tech in Communication Systems in the Department of Electronics and Communication Engineering, National Institute of Technology (NIT), Tiruchirappalli, India. His research interests include Cooperative Communication, orthogonal frequency division multiplexing (OFDM), multiple-input and multiple-output (MIMO) systems and Implementation on real time wireless platform.

P Muthuchidambaranathan received his B.Eng. Degree in Electronics and Communication Engineering from Government College of Technology, Coimbatore, India, in 1992, the M.Eng. Degree in Microwave and Optical Engineering, from A.C. College of Engineering and Technology, Karaikudi, India, in 1994. He obtained his Ph.D. degree in optical communication from the National Institute of Technology (NIT), Tiruchirappalli, India in 2009. He is currently working as an Associate Professor in the Department of Electronics and Communication Engineering, National Institute of Technology (NIT), Tiruchirappalli, India. His research interests include wireless communications, and optical communications. He published his research papers in refereed international journals, and international and national conferences. He is an author of the textbook “Wireless Communications”(published by Prentice Hall of India).