INVESTIGATION ON THE EFFECT OF USER POSITION IN MIMO COGNITIVE RADIO SYSTEMS WITH OVERLAPPING SPECTRUM SHARING

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ABSTRACT

Currently, the wireless communication system is developed and continuously improved due to the need of user services including the development of many new applications. This results in more consumption of frequency resource until it will not be enough to use in the future. One problem is that the spectrum possession of the licensed users is inefficiently utilized. The spectrum sharing in cognitive radio technology can solve the above problems by allowing secondary user to access the same frequency as primary user in the same area, which is divided into two patterns by spectrum sensing. If it detects an idle channel, it will perform a non-overlapping spectrum sharing. In turn, if it detects an occupied channel, it will continue to perform an overlapping spectrum sharing. In this paper, the guidelines for self-evaluation of the cognitive radio network is proposed to judge whether it is in the range of communication or not. The proposed concept must be designed to minimize the effect on the communication of primary network. The simulation results indicate the specific areas for cognitive radio that can be successfully implemented. The proposed work is very helpful for service providers to obtain more benefit from their limited resources.

1. INTRODUCTION

The process of cognitive radio systems is to communicate and adjust the parameters to suit the changed environment. Spectrum sensing is the main key of cognitive radio technology that search for available channels from the use of the Primary User (PU), then allow Secondary Users (SUs) to access those channels. In [1], the work has presented the optimization techniques for spectrum sensing by using cooperation of node clusters, that each node has only one antenna. By the data processing is separated into hierarchies. On the first level, all of the member nodes use the Equal Gain Combining (EGC) technique, then next, on the second level, will bring the data from each group into the processor by statistical decision, MAJORITY rule. But the research of the authors earlier, the work has supported the Multiple-Input-Multiple-Output (MIMO) technology. By applying the above techniques with MIMO technology to make the new technique named as MAJORITY++ Rule with Soft Decision (MJS++), it can operate by just one node to utilize many antennas in order to replace many nodes. In Fig. 2, it can be seen that the spectrum sensing by the new proposed technique outperform the others. At the 90% probability of detection, the MJS++ technique can reduce the chance of false alarm from 50% of ED technique to 26%. This 24% improvement can indicate the success of proposed technique for practical non-overlapping spectrum sharing.

However for spectrum utilization worth more, SU can perform a good communication while being a little interferer to PU on the overlapping scheme. The overlapping spectrum sharing allows SUs to reserve access the same spectrum along with PU but with one strict condition that the received signal of PU must to be under the acceptable level of interference. The work in [2] has presented the interference reduction method in spectrum sharing by the proper designs on transmit and receive beams of MIMO technology. The work in [3] has presented the power constraint techniques of the interference signals to PU in spectrum sharing. By comparing the interference power [4], the performance analysis of the transmit power constraint in spectrum sharing is introduced by a transmit antenna selection at secondary transmitter and the maximum ratio combining at secondary receiver, same as [5] but the performance analysis was in forms of the bit error rate and the channel capacity under two power constraint methods, including the mean value-based power allocation scheme and the channel state information-based power allocation scheme.

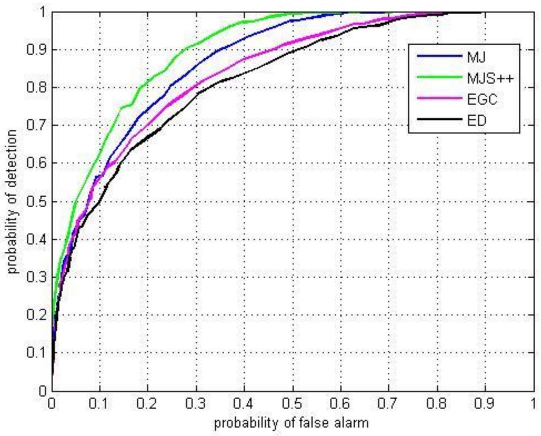

Fig. 1 Comparison of ROC curves for normal ED at $M = 1$, and EGC, MJ, MJS++ at $M = 4$.

So far in literature reviews, there is still no any work that focuses on the self-evaluation guidelines to consider whether the position of SU is suitable to make a good communication as well as interfere to PU under the acceptable limits of overlapping spectrum sharing scheme. The authors realize the need to initiate research on the impact of node positions in cognitive radio systems, and develop self-evaluation technique of secondary network in the system with the above position information in order to enable cognitive radio system for actually operating in practice.

2. PERFORMANCE ANALYSIS

2.1 System Model

This paper considers the overlapping cognitive network that the secondary link is composed of secondary transmitter (ST) and secondary receiver (SR), equipped with N and M antennas, respectively. The primary link is composed of only one antenna for both primary transmitter (PT) and primary receiver (PR). This paper defines that PR is the base station (BS) and SR is the fusion center (FC). The channel coefficient h_{kj} is the channel between k^{th} antenna of ST and j^{th} antenna of SR, the channel coefficient h_{kp} is the channel between k^{th} antenna of ST and PR, the channel coefficient h_{pj} is the channel between PT and j^{th} antenna. All channels are modeled as flat fading and Rayleigh distribution with variances λ_s, λ_p and λ_{ps}, respectively.

Between the transmission slots of ST, one of N antennas will be chosen through the ratio selection criterion, as following

$$s = \arg\max_{k}\left(\frac{g_{ks}}{g_{kp}}\right), \tag{1}$$

where $g_{ks} = \sum_{j=1}^{M}\left|h_{kj}\right|^2$ and $g_{kp} = \left|h_{kp}\right|^2$. By obtaining the bit error rate, the analysis will start with CDF of channel gain from ST to SR, $g_{ss} = \sum_{j=1}^{M}\left|h_{sj}\right|^2$, when use the ratio selection criterion in (1), are given by

$$F_{g_{ss}}(x) = \frac{1}{\Gamma(M+1)}\left[\left(\frac{x}{\lambda_s}\right)^{MN}\Gamma\left(1-M(N-1),\frac{x}{\lambda_s}\right)+\gamma\left(M+1,\frac{x}{\lambda_s}\right)\right], \tag{5}$$

where $\Gamma(.)$ is the gamma function. $\Gamma(.,.)$ and $\gamma(.,.)$ is the upper and lower incomplete gamma functions, that is obtained from [6, Eq. 8.350.2] and [6, Eq. 8.350.1], respectively.

On the other hand, for spectrum sharing, it needs to has the statistic values of ST-PR link, when $g_{sp} = \left|h_{sp}\right|^2$, will be the PDF of g_{sp}.

$$p_{g_{sp}}(y) = \frac{N\Gamma(MN)}{\Gamma(M)\Gamma(M(N-1))}\sum_{i=0}^{M(N-1)-1}\binom{M(N-1)-1}{i}\times(-1)^i\frac{y^{M+i}}{\lambda_p^{M+i+1}}\Gamma\left(-M-i,\frac{y}{\lambda_p}\right), \tag{6}$$

It also provides the combined signal to noise ratio (SNR), that SR use the power allocation [5, Eq. 12], as given by

$$\gamma_{ss} = \min\left(\frac{I}{\mathbb{E}(g_{sp})},\bar{\gamma}\right)\lambda_s, \tag{7}$$

where $\bar{\gamma} = \frac{P_m}{N_0}$ at P_m is the maximum transmit power constraint of PT and ST, N_0 is the noise variance, I is the limited level of interference of secondary user, and

$$\mathbb{E}(g_{sp}) = \frac{N\Gamma(MN)\lambda_p}{\Gamma(M)\Gamma(M(N-1))}\sum_{i=0}^{M(N-1)-1}\frac{\binom{M(N-1)-1}{i}(-1)^i}{M+i+2}, \tag{8}$$

that is given from (6), where $\mathbb{E}(.)$ is the expectation operator.

By the way, performance analysis is divided into two cases based on the concentration of interference by distance.

2.2 Performance Analysis without Interference from PT-SR

First case, when interference from PT-SR is ignored, that PT is far from SR, there is very little interference from PT, which the secondary outage probability can be defined as

$$P_{out} = \Pr[\gamma_{ss} < x] = F_{g_{ss}}\left(\frac{x}{\min\left(\frac{I}{\mathbb{E}(g_{sp})},\bar{\gamma}\right)}\right), \tag{9}$$

where $x = 2^R - 1$ and R is the transmission rate. To yield the typical result for obtaining the end-to-end BER in terms of SNR, the expression is given by

$$P_{s,sys} = -\int_0^{\infty}\frac{d}{d\gamma}P_e(x)F_{\gamma}(x)dx, \tag{10}$$

where $F_\gamma(.)$ is the CDF in terms of SNR of any case, and $P_e(.)$ is the condition error probability (CEP) that based on the used modulation scheme, as expressed by

$$P_e(x) = a\mathrm{Q}\left(\sqrt{bx}\right), \tag{11}$$

where a and b are the modulation-specific constants, such as $(a, b) = (1,2)$ for BPSK, $(a, b) = (1,1)$ for BFSK, and $(a, b) = \left(\frac{2(m-1)}{m}, 6\log_2\frac{(m)}{(m^2-1)}\right)$ for m-PAM. And $\mathrm{Q}(.)$ is the Gaussian Q-function.

Consider the CDF of g_{ss} in (9), the BER of this case are as follow

$$P_s(a, b) = \frac{a}{2}\sqrt{\frac{b}{2\pi}}\int_0^\infty \frac{e^{-\frac{b}{2}x}}{\sqrt{x}} F_{g_{ss}}\left(\frac{x}{min\left(\frac{I}{\mathbb{E}(g_{sp})}, \bar{\gamma}\right)}\right) dx, \tag{12}$$

so the BER in (12) can be written in the closed form as

$$P_s(a, b) = \frac{\Gamma\left(M+\frac{3}{2}\right)}{\Gamma(M+1)} \frac{\frac{a}{2}\sqrt{\frac{b}{2\pi}}\left(\frac{1}{\gamma_{ss}}\right)^{1+M}}{\left(\frac{1}{\gamma_{ss}}+\frac{b}{2}\right)^{M+\frac{3}{2}}} \times \left[\left(\frac{1}{MN+\frac{1}{2}}\right) {}_2F_1\left(1, M+\frac{3}{2}; MN+\frac{3}{2}; \frac{b\gamma_{ss}}{2+b\gamma_{ss}}\right) + \left(\frac{1}{1+M}\right) {}_2F_1\left(1, M+\frac{3}{2}; M+2; \frac{2}{2+b\gamma_{ss}}\right)\right], \tag{13}$$

where ${}_2F_1(.,.:.:.)$ is the hypergeometric function [6, Eq. 9.14.2].

2.4 Performance Analysis with Interference from PT-SR

In the second case, the appearing of interference from primary user. The combined signal to interference plus noise ratio (SINR) at SR when the s^{th} antenna selected at ST are $\gamma_{int} = \frac{\gamma_{ss}}{\bar{\gamma} g_I + 1} = \frac{\gamma_{ss}}{\gamma_I + 1}$, where $g_I = \frac{\left|\sum_{j=1}^{M} h_{sj}^* h_{pj}\right|^2}{g_{ss}}$ with the PDF $p_{g_I}(y) = \frac{1}{\lambda_{ps}} e^{-\frac{y}{\lambda_{ps}}}$, so the CDF of γ_{int} can be shown as

$$F_{\gamma_{int}}(x) = \Pr[\gamma_{int} < x] = F_1(x) + F_2(x), \tag{14}$$

by $F_1(.)$ and $F_2(.)$ can be defined from the PDF $p_{\gamma_I}(y) = \frac{e^{-\frac{y}{\gamma_{ps}}}}{\gamma_{ps}}$ at $\gamma_{ps} = \lambda_{ps}\bar{\gamma}$. The CDF of γ_{int} can be written as

$$\Pr[\gamma_{int} < x] = \mathbb{E}_{\gamma_I}\left[F_{g_{ss}}\left(\frac{x(y+1)}{\min\left(\frac{I}{\mathbb{E}(g_{sp})}, \bar{\gamma}\right)}\right) | \gamma_I = y\right]. \tag{15}$$

then defined $F_1(.)$ as

$$F_1(x) = \int_0^\infty \frac{\left(\frac{x(y+1)}{\gamma_{ss}}\right)^{MN}}{\Gamma(M+1)} \frac{e^{-\frac{y}{\gamma_{ps}}}}{\gamma_{ps}} \Gamma\left(1 - M(N-1), \frac{x(y+1)}{\gamma_{ss}}\right) dy \tag{16}$$

so, $F_1(x)$ is as

$$F_1(x) = \frac{(-1)^{M(N-1)} e^{\frac{1}{\gamma_{ps}}} \left(\frac{\gamma_{ps}}{\gamma_{ss}}\right)^{MN}}{\Gamma(M+1)(M(N-1)-1)!} \left[\Gamma\left(MN+1, \frac{1}{\gamma_{ps}}\right) x^{MN} \times \mathrm{Ei}\left(\frac{-x}{\gamma_{ss,MV}}\right) + (MN)! \sum_{k=0}^{MN} \frac{\left(\frac{1}{\gamma_{ps}}\right)^k}{k!} x^{MN} \left(\frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right)^{-k} \times \Gamma\left(k, \frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right)\right] + \frac{\left(\frac{1}{\gamma_{ps}}\right) e^{\frac{1}{\gamma_{ps}}}}{\Gamma(M+1)(M(N-1)-1)!} \times \sum_{k=0}^{M(N-1)+k} (-1)^{M(N-1)+k} k! \left(\frac{x}{\gamma_{ss}}\right)^{MN-k-1} \times \left(\frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right)^{k-MN} \Gamma\left(MN-k, \frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right), \tag{17}$$

where $\mathrm{Ei}(.)$ is the exponential integral function. And defined $F_2(.)$ as

$$F_2(x) = \int_0^\infty \frac{\gamma\left(M+1, \frac{x(y+1)}{\gamma_{ss}}\right)}{\Gamma(M+1)} \frac{e^{-\frac{y}{\gamma_{ps}}}}{\gamma_{ps}} dy, \tag{18}$$

so, $F_2(x)$ is as

$$F_2(x) = \frac{\left(\frac{1}{\gamma_{ps}}\right) e^{\frac{1}{\gamma_{ps}}} M!}{\Gamma(M+1)} \left[\gamma_{ps} e^{-\frac{1}{\gamma_{ps}}} - \sum_{k=0}^{M} \frac{\left(\frac{x}{\gamma_{ss}}\right)^k}{k!} \times \left(\frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right)^{-k-1} \Gamma\left(k+1, \frac{1}{\gamma_{ps}} + \frac{x}{\gamma_{ss}}\right)\right]. \tag{19}$$

Finally, the BER obtained by replacing (14) in (12), are as follow

$$P_{Int}(a, b) = \frac{a}{2}\sqrt{\frac{b}{2\pi}} \int_0^\infty \frac{e^{-\frac{b}{2}x}}{\sqrt{x}} F_{\gamma_{int}}(x)\, dx, \tag{20}$$

so, the BER result form is

$$P_{Int}(a, b) = \frac{a}{2}\sqrt{\frac{b}{2\pi}} \frac{1}{\Gamma(M+1)} [I_1 + I_2 + I_3 + I_4], \tag{21}$$

that I_1, I_2, I_3 and I_4 are the sub-function, that have the result forms in (22), (23), (24) and (25), respectively

$$I_1 = \frac{(-1)^{M(N-1)+1}}{(M(N-1)-1)!} e^{\frac{1}{\gamma_{ps}}} \left(\frac{\gamma_{ps}}{\gamma_{ss}}\right)^{MN} \times \frac{\Gamma\left(MN+1, \frac{1}{\gamma_{ps}}\right)\Gamma\left(MN+\frac{1}{2}\right)}{\left(MN+\frac{1}{2}\right)\left(\frac{1}{\gamma_{ss}}+\frac{b}{2}\right)^{MN+\frac{1}{2}}} \times {}_2F_1\left(1, MN+\frac{1}{2}; MN+\frac{3}{2}; \frac{b\gamma_{ss}}{2+b\gamma_{ss}}\right), \tag{22}$$

$$I_2 = (-1)^{M(N-1)} (MN)!\, \Gamma\left(MN+\frac{1}{2}\right) e^{\frac{b\gamma_{ss}+2}{4\gamma_{ps}}} \sum_{k=1}^{MN} \frac{(k-1)!}{k!} \times \sum_{m=0}^{k-1} \frac{\left(\frac{1}{\gamma_{ps}}\right)^m}{m!} \left(\frac{1}{\gamma_{ss}} + \frac{b}{2}\right)^{-\frac{1}{2}\left(MN+m-k+\frac{3}{2}\right)} \left(\frac{\gamma_{ss}}{\gamma_{ps}}\right)^{\frac{1}{4}(2k+2m-2MN-1)} \times \mathrm{W}_{\frac{1}{2}\left(m-k-MN-\frac{1}{2}\right), -\frac{1}{2}\left(MN+m-k+\frac{1}{2}\right)}\left(\frac{b\gamma_{ss}+2}{2\gamma_{ps}}\right) \tag{23}$$

where $W_{\lambda,\mu}(.)$ is the Whittaker W-function.

$$I_3 = \left(\frac{1}{\gamma_{ps}}\right) e^{\frac{b\gamma_{ss}+2}{4\gamma_{ps}}} \sum_{k=0}^{M(N-1)-2} (-1)^{M(N-1)+k} k!\,(MN-k-1)!\,\Gamma\left(MN-k-\frac{1}{2}\right) \sum_{m=0}^{MN-k-1} \frac{\gamma_{ss}{}^{1-m}}{m!} \left(\frac{1}{\gamma_{ss}}+\frac{b}{2}\right)^{-\frac{1}{2}\left(m+\frac{1}{2}\right)} \times \left(\frac{\gamma_{ss}}{\gamma_{ps}}\right)^{\frac{1}{2}\left(m-\frac{3}{2}\right)} W_{\frac{1}{2}\left(2k-2MN+m+\frac{3}{2}\right),\frac{1}{2}\left(-m+\frac{1}{2}\right)} \left(\frac{b\gamma_{ss}+2}{2\gamma_{ps}}\right) \tag{24}$$

$$I_4 = M!\left[\sqrt{\frac{2\pi}{b}} - \left(\frac{1}{\gamma_{ps}}\right) e^{\frac{b\gamma_{ss}+2}{4\gamma_{ps}}} \sum_{k=0}^{M} \Gamma\left(k+\frac{1}{2}\right) \sum_{m=0}^{k} \frac{\gamma_{ss}{}^{-m+1}}{m!} \left(\frac{1}{\gamma_{ss}}+\frac{b}{2}\right)^{-\frac{1}{2}\left(m+\frac{1}{2}\right)} \left(\frac{\gamma_{ss}}{\gamma_{ps}}\right)^{\frac{1}{2}\left(m-\frac{3}{2}\right)} W_{\frac{1}{2}\left(m-2k-\frac{1}{2}\right),\frac{1}{2}\left(-m+\frac{1}{2}\right)} \left(\frac{b\gamma_{ss}+2}{2\gamma_{ps}}\right)\right] \tag{25}$$

3. SIMULATION RESULTS AND DISCUSSION

Assuming the primary network use the m-QAM modulation which m is constellation size and G_c is the coding gain, BER of the primary network can be approximately expressed by

$$P_b \approx 0.2e^{-1.5\left(\frac{\bar{\gamma}G_c}{m-1}\right)}, \tag{26}$$

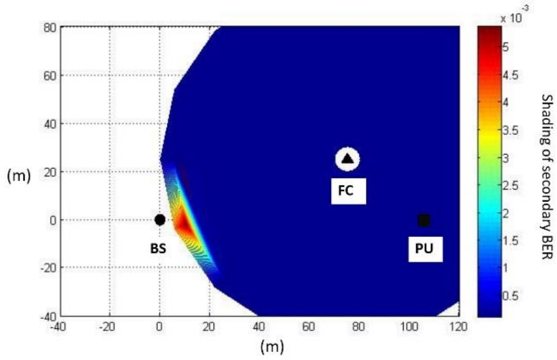

Fig. 2 BER region of secondary network on downlink operation.

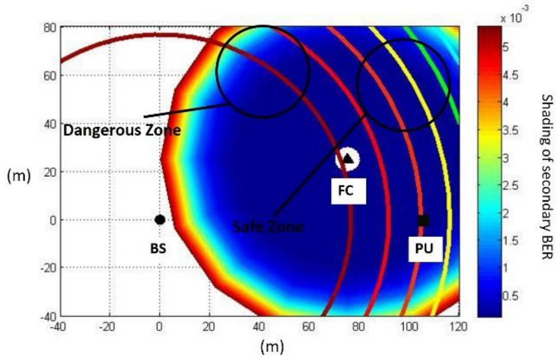

Fig. 3 BER regions of primary network and secondary network on uplink operation.

Fig. 2 shows the BER region of secondary network on downlink operation and Fig.3 shows the BER radius of primary network made obtained by (26) due to the interference from ST nearby interfaced with the BER regions of primary network and secondary network on uplink operation. The considered spectrum has the carrier frequency $f_c = 2.1$ GHz. PU is far from BS with $R_p = 105$ m, $P_m = 23$ dBm, and $G_c = 6$ dB. The dangerous zone is the area that the bit error rates of both primary and secondary networks are more than 10^{-3}. The safe zone is the area that the bit error rates of both primary and secondary networks are less than 10^{-3}. From both figures, the results can be a good guideline to make a decision whether SU can perform the overlapping spectrum sharing or not. If the location of SU is in the safe zone, then the overlapping scheme can be used.

CONCLUSION

The paper has addressed many proposed techniques in the areas of MIMO cognitive radio systems in order to provide a good guideline for researchers to develop the practical use of efficient spectrum sharing. The study goes further on the impact of node position. This is to know whether the secondary user is in the suitable position for communication or not. Also the study can suggest adjusting the transmission power appropriately. Moreover, the results show the impact on position of each node in cognitive radio system. This is very helpful to be the guideline to create self-evaluation method for secondary networks in order to make the right decisions in communication, and to acquire the efficiently spectrum sharing.

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