Response to Reviewers' Comments:
Manuscript ID: ID 92

Selection of Appropriate Number of CRs in Cooperative Spectrum Sensing Over Suzuki Fading

September 3, 2015

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Dear Prof. Nguyen Thanh Thuy and Prof. Xuan-Tu Tran,

Please find enclosed the revision of our paper "Selection of Appropriate Number of CRs in Cooperative Spectrum Sensing Over Suzuki Fading" with Manuscript ID: 92.

We would like to thank you for handling the review process of our paper. We are also indebted to the reviewers for their helpful comments. In this revision, all of the comments raised have been addressed. A detailed point-by-point response to the comments is given below.

Yours sincerely,

Thai-Mai DINH THI, Thanh-Long NGUYEN and Quoc-Tuan NGUYEN.

Note: To help legibility of the remainder of this response letter, all the reviewers' comments and questions are typeset in *italic font*. Our responses and remarks are written in plain font. Rephrased sentences are typeset in *red*

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Authors' Response to Reviewer B

We would like to thank the reviewer for valuable and constructive comments and suggestions. We have revised the paper in line with the reviewer's comments, thereby improving the contributions and the clarity of the paper accordingly.

Comment 1:
In Section 3.1, the authors should clarify (with a sentences for example) the fact that these results comes from [5] (I understand that it is the case).

Response:
Thank you for this valuable comment. We have made the following changes in the revised manuscript:

Page 3, paragraph 1 of Sec 3 - Local Spectrum Sensing

"As presented in [5], there are several key parameters used to evaluate detection performance of local spectrum sensing, such as: probability of detection, P_d, probability of false-alarm, P_f, and probability of missed detection, P_m. Probabilities of detection and false-alarm are defined as follows [5]"

Page 3, paragraph 2 of Sec 3 - Local Spectrum Sensing

The relation between P_d and P_f is given by [5]:

$$P_d = Q_m\left(\sqrt{2m\gamma}, \sqrt{G_m^{-1}(P_f)}\right) \tag{3}$$

Comment 2: *In Figure 3, why simulation of the pdf is shown? The pdf is given in Equation (5), there is no need to simulate it. So, I suggest to show only the theoretical form.*

Response:
We would like to thank reviewer for the positive comment. We simulate the pdfs of the envelope and the power gain of Suzuki channel with aims to show the rightness of the known theory. However, we have excluded the simulated curves as the reviewer's comment.

Page 4, Figure 3

Please see Figure A1 below

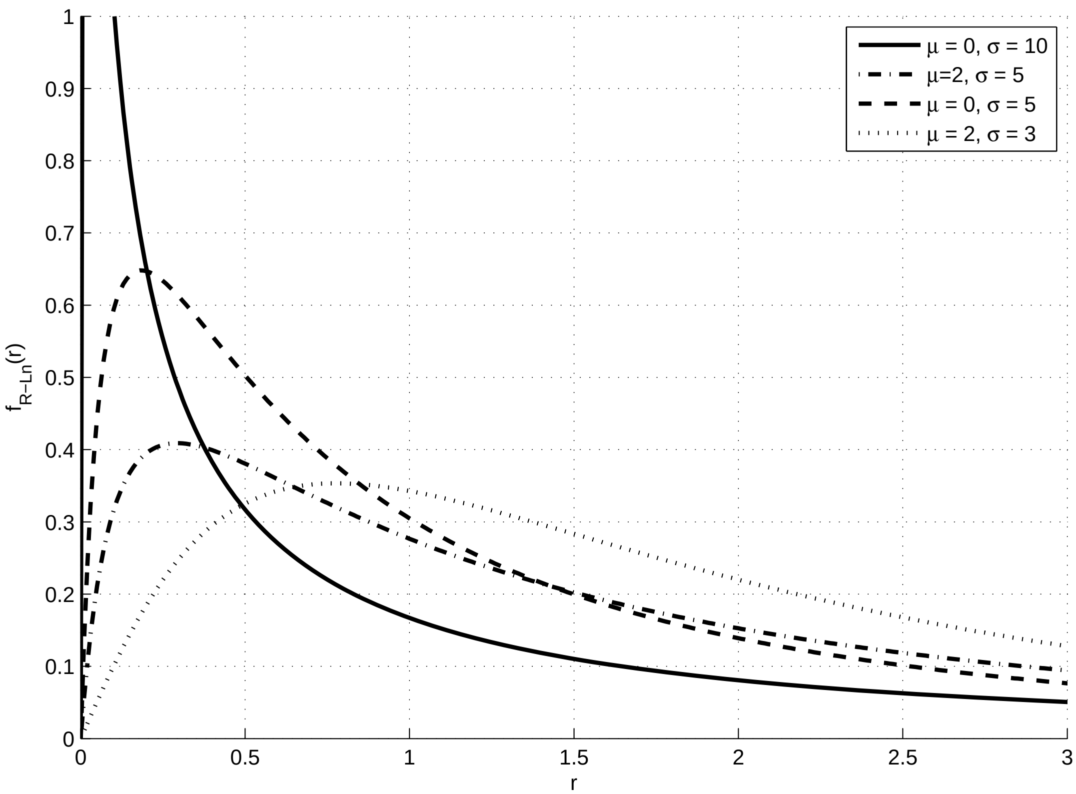

Figure A1: The pdf of the envelope of Suzuki channel

Comment 3:
Same question for Figure 4. If in this case, it may be interesting to show some simulations, please explain why, and explain what do you simulate exactly. If it is exactly the model, from my point of view there is no benefit.

Response:
Thank you for your comment. The answer for this question is presented in Comment 2. However, in this case, we have not only excluded the simulated curve but also added more theorical curves corresponding to different values of μ and σ in Figure 4.

<u>Page 4, Figure 4</u>

Please see Figure A2 below

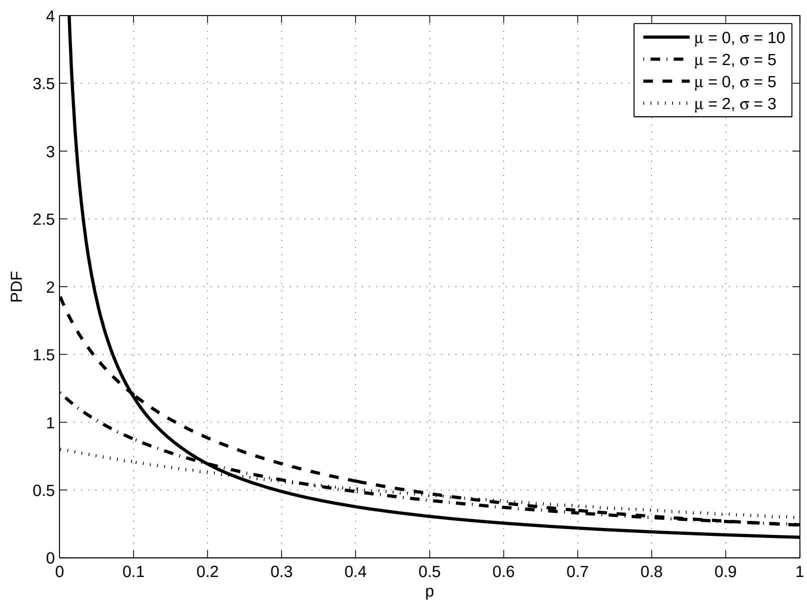

Figure A2: The pdf of the power gain of Suzuki channel

<u>Page 4, Column 2, Paragraph 1</u>

"Figure 4 illustrates the pdfs of the power of the Suzuki channels for different values of μ and σ in dB unit."

Comment 4:
After the sentence "Figures 7 and 8 show that among...OR rule always gives us the best detection performance", you need to explain why. You have to give the intuitive or the

formal reasons of this result.

Response:
We would like to thank the reviewer for this valuable suggestion. We have the following change:

> Page 6, Column 1, Paragraph 3
>
> "For OR rule, the FC decides H_1 when there is at least one CR user detects primary user signal, otherwise, it needs more than one. This leads to detection performance of OR rules better than other rules. "

Comment 5: *The results and the comparison with the two other kind of fading (LogN and Rayleigh) should be more detailled. The authors should explain what are the differences with the two other fading, what does it involve for the detection of the primary signals and why. The explanation in the last paragraph before the conslusion "it is more complicated than its component channels" is not satisfactory. Explain also what are the parameters of the different fadings, is it the same moments for the three fadings (mean, variance, maybe the 3rd moment and so on)? Is it these parameters that makes the performance of the Suzuki fading lower (for the same mean, is the variance greater ?)...*

Response:
We would like to thank the reviewer for this valuable comment. In the revised manuscript, we have made the following changes:

> Page 8, column 1, paragraph 2:
>
> "For comparison purposes, we also provide the detection performance vs. number of CRs under Rayleigh and Lognormal channels in Figure 12. Note that, the average power gains of three kinds of fadings are the same, i.e, $\overline{p}_{Suzuki} = \overline{p}_{Rayleigh} = \overline{p}_{Lognormal}$, in which Suzuki and lognormal variables have the same Gaussian parameters with $\mu = 2$ dB and $\sigma = 5$dB. As can be seen from this figure, Rayleigh and Lognormal channels require fewer CRs taking part in the cooperative spectrum sensing process than Suzuki channel. This is because Suzuki channel is the composition of both Rayleigh and lognormal channels and therefore, it is more complicated than its component channels. In details, the considered Suzuki variables consist of two components: lognormal variable which has the same average power gain and Rayleigh one with average power gain equal to 1 (i.e. 0 dB) as mentioned in Section 3.2. Rayleigh component is the cause of the degradation in detection performance of cooperative spectrum sensing under Suzuki fading when compared to that under lognormal fading which have the same average power gain. The results above are compatible with the characteristics and the complexity of these three channels."

Comment 6:

Future works are missing

Response:

Thank you for your valuable suggestion, we have made changes in the revised manuscript as follows.

> Page 8, column 1, Section 5, paragraph 2:
>
> "In constraint of the paper, we only consider performance of cooperative spectrum sensing with assumption of free-loss physical links between cooperating CRs and FC which are so-called reporting channels. The effect of Suzuki fading on these channels for investigating cooperative detection performance will be taken into account in further work. "

Comment 7:

The typos:
Page 1: can achive → can achieve ; require a date rate to 10MHz → require a data rate of 10Mbit/s? ; leads to the lack → and leads to the lack.
Page 2: An question arises → A question arises; At least how many CRs are there in order to avoid → what is the required number of CRs to avoid ... ; Next, → Then,
Page 3: a reference in colum 2 (Gamma function) does not work.
Page 4: the of pdf the power gain ???
Page 5: ascissas ; a point at the end of this paragraph is missing.
Page 6: is alaways the biggest headache ...→ please be more formal ; in more detail → in more details.
So you need to use a use a spell checker to correct the typos that I have not seen.

Response:

Thank you for your advice, we have already corrected them all.

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Authors' Response to Reviewer C

We would like to thank the reviewer for valuable and constructive comments and suggestions. We have revised the paper in line with the reviewer's comments, thereby improving the contributions and the clarity of the paper accordingly.

General Comment:
This paper presented the performance analysis of cooperative spectrum sensing over Suzuki fading channels based on hard-decision combining rule in cognitive radio. Besides, it also proposed a method that can find the minimum number of cognitive radio users attending in cooperative spectrum sensing to reduce the overhead of network.

Response:
We would like to express our sincere thanks to the reviewer for summarizing our paper and your appreciation.

Comment 1:
However, there is a most important point should be clarified that is the convergence of algorithm as figure 10 (page 7). The authors should prove the convergence of this algorithm.

Response:
Thank you so much for your valuable comment. In this paper, for simplicity, we only consider the selection of appropriate number of CRs in cooperative spectrum sensing using OR rule (Please see the captions of Figure 11 and Figure 12). For OR rule, equation (15) can be re-written as follows:

$$Q_d = \sum_{i=1}^{n} C_n^i P_d^i (1 - P_d)^{n-i} = 1 - (1 - P_d)^n \geq 1 - \varepsilon$$

Therefore, equation (16) becomes:

$$\varepsilon \geq 1 - Q_d = Q_m = (1 - P_d)^n$$

As a result, we have (17) as follows:

$$n = \min\{\arg\{\varepsilon \geq Q_m\}\}$$

Clearly, $1 - P_d < 1$, then $(1 - P_d)^n \to 0$ if $n \to \infty$. For a small enough ε, we always find out a finite n that sastifies $\varepsilon \geq (1 - P_d)^n$. That means the algorithm is converged.
We have made the following changes in the revised manuscripts:

> Page 6, Section 4.2
>
> "In this section, we will propose a formula to find out a suitable number of cooperative CRs to avoid overhead to the network but still guarantee the detection performance with assumption that FC uses OR rule to make a global decision. Equation (12) can be rewritten as follows:
>
> $$Q_d = 1 - (1 - P_d)^n \qquad (15)$$
>
> We observe that as $n \mapsto \infty$: $Q_d \mapsto 1$. Let ε be a very small number so that when n increases to a certain value, the condition $1 - Q_d < \varepsilon$ is always satisfied. Thus,
>
> $$Q_d = \sum_{i=1}^{n} C_n^i P_d^i (1 - P_d)^{n-i} = 1 - (1 - P_d)^n \geq 1 - \varepsilon \qquad (16)$$
>
> or
>
> $$\varepsilon \geq 1 - Q_d = Q_m = (1 - P_d)^n \qquad (17)$$
>
> Generally, the formula of the number of CRs joining cooperative spectrum sensing is
>
> $$n = \min\{\arg\{\varepsilon \geq Q_m\}\} \qquad (18)$$
>
> For a given value of ε, we can apply the following algorithm to compute the minimum value of n satisfying (18) "

Comment 2:
Furthermore, many of the references are quite old. The authors should refer some newer works about these problems.

Response:
We are thankful to the reviewer for the suggestion. However, we would like to remains list of references because those documents are suitable for our research.

Comment 3:
Finally, there are many typos in this paper.

Response:
We sincerely thank the reviewer for this valuable comment. We have corrected them all.