A New Game Theory Approach for Noise Reduction in Cognitive Radio Network

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Abstract— Noise reduction is one of the fundamental signal processing functions of the cognitive radio system, as noise affects data integrity and obscures the using of the unused channels in the licensed spectrum of Primary Users (PU). The majority of traditional filter methods handles only specific types of noises in a certain range of frequencies. Despite the intensive research in this area, building accurate noise reduction engines that equilibria between signal-to-noise ratio and computational cost remain a holy grail. In this paper, we made our initial effort towards this issue by building a novel game theory engine for effective noise reduction that incorporates the advantage of both adaptive filtering and wavelet denoising strategies. Adaptive filter solves the convergence problem and low mean square error rate. Wavelet transform as a nonstationary signal analysis can describe signal's local features either spatially or spectrally and obtains the asymptotically optimal estimation of original signals. Game theory (GT) is adapted for optimal decision making under competition; so that it chooses the best strategies to achieve the best noise reduction equilibrium when others are affected by the decision of the individual player, as the experiments indicate that the proposed model on its ability to reduce noise significantly.

Keywords—noise reduction, cognitive radio, game theory adaptive filter, wavelet transform.

I. INTRODUCTION

In the communication system, signals are often contaminated by noise during transmission, their collection, and processing; this unwanted signal can have degraded the original signal that affects the performance of data transmission between a sender and a receiver. The key issues of signal processing are to eliminate the noise and retain the original signals' details. To get rid of the noise, filters are employed in communication system [1][2]. These filters can be built either by hardware components, which lead to costly and bulky systems that can only filter specific frequencies or soft-ware-based systems that enable re-configurability by utilizing multi-purpose digital programmable devices for signal processing instead of specifically de-signed hardware. However, new technologies such as Cognitive Radio (CR) will handle the wide band of frequencies in different environments and should have the ability to de-noise signals of any frequency [3].

Recently, many researchers have suggested lots of denoising methods for CR communication systems that can be divided into three categories: (1) Time frequency analysis, (2) Matrix factorization, and (3) Adaptive filter based techniques [4][5]. Time-frequency denoising techniques allow inspection of the noise-induced signal in both time and frequency domain (e.g. wavelet transform). The next category offers the means to accomplish signal space analysis accomplished of factorizing an enormous or sparse matrix into smaller data sets, which lets easier examination of a signal (e.g. singular value decomposition). The third category performs noise cancellation by employing filters with adaptive algorithms. Filters rely on the idea of running through the signal entry by entry "window", replacing each entry with the specific function output depending on the neighboring entries. For 1 Dimension signals, the clearest window is just the first little preceding and subsequent entries. In the literature, the most popular filters include the median filtering, kalman filtering, and the moving average filtering [4].

There are still many challenges to achieve a more accurate signal denoising in CR communication system because in CR the noise can be generated from many re-source such as the interference affected when the spectrum sense multiple bands over the same period. The noise source may be from the secondary injector which synchronizes in time and frequency [6]. Some traditional filters have failed to achieve what is known as the global optimization solution. Also, the problem of some of these filters depends on the initial variables in the start-up stage. Furthermore, the majority of these algorithms till now are noise dependent; for example, the median filter performs good with salt and pepper noise, whereas in removing Gaussian noise and speckle noise the wavelet transform per-forms better than other because It has unique signal analysis [7].

Optimization is a very significant study area in applied mathematics [8]. Optimization algorithms purpose to find the finest values for a system 's parameters under various condition. The first step in resolving an optimization problem is defining the objective function that states the relation between the parameters and constraints of the system. Numerous optimization techniques are recently accompanying with signal denoising for the purpose of reducing the noise that is still present in the signal, the weight of the coefficients of the adaptive filters is detected to be the optimal weight [9]. This approach is very likely to achieve the optimal global solution by self-stimulation in the work environment in order to save itself among others, for example, the swarm intelligence of the masses of the old environments in this case [10] [11].

Game theory is broadly accepted as a vital tool in resolving complex optimization issues. The inner consistency and mathematical basis of game theory make it a master tool for modeling and designing automated decision-making operation in interacting environments [12]. Anytime we have a case with two or more agents that involves known payouts or quantifiable outcome, we utilize game theory to help locate the most likely outcomes [13]. For signal denoising problem, game theory can be exploited as a local autonomous decision taken by the players in which samples in the signal are modeled as autonomous players that aim to maximize the outcome for set of various strategies. The essential difference between the evaluation algorithm techniques and game theory is that the first tries to find the optimal solution with particular parameters, but the game theory is used to make a decision based on the utility function.

The main intention of this paper is to study about how effectively the spatial filtering, transform filtering, and game theory as decision maker can be used all together to improve the availability of the communication system by noise reduction; so that much signal can be processed and transmitted. This new system ensures the selection of the best available methods to reduce signal's noise based on the comparison between a set of different strategies for each method. These strategies consider the process of parameters adjustment based on signal content (context of the signal) to achieve dynamically with the signal environment. It is also noted that the improvement in performance is due to the improvement of parameters in a perfective manner, which showed the possibility of the proposed model significantly. Furthermore, it can be expanded by considering other denoising approaches as players to make a more accurate decision (i.e. scalable) based on more comparative strategies. To the best of our knowledge based on google search engine, this is the first work that utilizes game theory as a decision-making tool to remove noise from cognitive radio.

This paper contributes to the field in two idiosyncratic ways; firstly, by examining the potential of GT to select the optimal denoising parameters among alternatives, instead of fusion of two or more algorithms. Thus eliminating the need for the fusion computational cost. Secondly, by the way the GT is applied, by introducing the denoising as a player in GT.

The rest of the paper is organized as follows. Section 2 literature survey. The full description of the proposed algorithm has been made in Section 3. In Section 4, discussions and the results on the dataset are given. Finally, conclusions are drawn in Section 5.

II. LITERATURE SURVEY

Over the years, many approaches have been developed to solve noise reduction problem in CR network. Researchers have also made great efforts to improve the performance of the signal denoising; however, it is still difficult problem to solve for wideband signals. In a recent study [14], the work explored the wavelet trans-form for signal denoising. In 1-D wavelet noise cancellation model, noise reduction processing was carried out in each spectrum sensing node while in 2-D wavelet noise reduction process was implemented on signals that were collected in the sensing station. Both systems employed the conventional cooperative energy spectrum sensing algorithm based on AND rule. 2-D noise reduction demonstrated much better performance than 1-D wave-let denoising, and the higher the level of wavelet transform the better of the sensing performance. However, identification of the most suitable wavelet mother kernel to achieve reasonable signal denoising in the form of PSNR remains an open problem.

Another trend to deal with wavelet-based signal denoising problem is based on softened hard decision that provide an excellent means to model the signal energy detector by introducing double threshold decision, The lower threshold is determined according to the minimum noise variation and the upper limit is selected according to the noise variance [15]. However, this technique requires a priori information to control thresholds that mainly depends on the user through trial and error.

With this same target in [16] a two-branch wavelet noise reduction to sense the spectrum hole under low SNR (signal to noise ratio) situation is introduced. A remarkable feature of this model is that it can eliminate the effect of noise through two-phase of noise reduction in each branch. By using band pass filter to determine Power Spectrum Density (PSD) values of the sub bands which are distinguished by the signal's particularity, the sub band with the minimal PSD value in all of the sub bands could be found. Then, the result of the two branches are combined and analyses in order to make the final decision. Finally, reconstruct the signal to further remove the noise and then accurately detect the spectrum holes. In practice, there is no ideal band pass filter. The filter does not attenuate all frequencies those are completely outside the desired frequency range.

Concurrently, in 2014 D. Martinez et al. [17] had examined the idea of uncertainty in the energy detectors for CR denoising. This denoising technique integrates a noise variance estimation that represents uncertainty in the noise power model for dynamically fitting the detection threshold to the power of the noise exist at the time of detection. The expected noise power level comes from the received signal samples using a group of high-pass filters and median filtering. However, the current uncertainty evaluation method depends on a measurement model relating the measured to input (influence) quantities; other exiting uncertainty evaluation approaches such as Monto Carlo provide more accurate assessment. Furthermore, using median filter can't distinguish fine detail from noise and given that high-pass filter is just a first-order filter, it may not give us a step enough cutoff frequency for the application.

In addition, a new CR denoising method based on slantlet transform is suggested on [18] for performance enhancing in the energy detection sensing . This algorithm uses filter bank transform to decompose the signal of PU into suit of coefficients, that decrease the complexity in comparison with the DWT. This reduction leads to decrease sensing time and consumed power of the SU. However, for a constant number of zero moments, slantlet transform cannot profit a discrete-time basis that is ideal with respect to time localization [19].

Another approach was introduced by J. Willem [20] defining a hybrid matrix factorization technique includes Non-negative matrix (NMF) factorization and singular value decomposition (SVD) to enhance the accuracy of spectrum sensing obviously by get rid of automatic gain control (AGC) noise in CR. In addition, they used a curve fitting way to locate the best number of components to be included for implementation of NMF. However, NMF is the complex algorithm to implement, and its convergence can be slow [21-22].

Although noise reduction in CR has been studied for nearly many years, there is still room to make it more efficient and practical in real application. According to the aforementioned review. It can be found that past studies were primarily devoted to: (1) Devising different technique of CR denoising that employ signal information (i.e. signal power, number of signal, modulation type, symbol rate and presence of interferer) (2) Not addressing the issues associated with the building of adaptive filter that can remove any types of noise in different bands (3) Most of the existing denoising methods depend on the fusion of two or more methods in a sequence manner. Yet the computational cost of fusion grows exponentially with the number of fused techniques. Therefore, the practical implementation of fusion algorithm is limited. However, to best of our knowledge, less attention has been paid to devising a new algorithm to select the optimal de-noising parameters among alternatives for noise cancellation based on single features. Here, the important of game theory is highlighted to deliver the finest set of strategies in form of decisions to instruct competitive behavior to a desirable outcome, and analysis of how a sequence of probable strategic changes can predict several competitive outcomes.

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III. The Proposed Noise Reduction System

This paper proposes a new method that utilizes game theory–based score level fusion to select the optimal parameters from alternative algorithms in the evaluation stage to cancel CR signal's noise. The proposed algorithm has been proto-typed using two types of denoising stimuli: wavelet transform and adaptive filtering. The game theory results indicate the strength of both stimuli for noise cancellation depending on the association between alternative parameters and CR signal context in deferent bands. The idea of wavelet filtering denoising relies on removing modulus maxima points of noise and retain only the modulus maxima points of a real signal. Whereas, the purpose of spatial adaptive filtering lies in finding the filter coefficients that relate to making the least mean square of the error signal. Fig. 1 shows the main system components and how they are linked to each other.

A. Adding Noise

our system investigates two types of signals (Wi-Fi 802.11a 5.8 GHz, 4G LTE) to cover both licensed, unlicensed frequency bands that can be used by CR systems. Wi-Fi 802.11a is available and supports high speeds data rate and has popular frequency band suitable for low cost wireless systems with less interference compared to 802.11b [23] [24]. The LTE signal is widely used in 4G mobile devices and data terminals[25]. Given these types of signals, the first step is to add noise. In our case, the signals are destroyed by the following two commonly widely noises: additive white Gaussian noise (AWGN) and Rayleigh noise to cover both of nonfading AWGN and fading channels; see [11] for more details.

B. Per- denoising processes

Herein, two signal de-nosing algorithms (one algorithm for each player) are implemented to prepare the different strategies for each player. The first algorithm relies on wavelet transform to detect noise and restores the original signal from received noisy signal. Discrete Wavelet Transform (DWT) is efficient when analyzing nonstationary signals because under the wavelet decomposition different scale has different time and frequency resolution [11]. In our case, several mother wavelet functions are chosen and each of them are represented as a strategy in our game. More

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information regarding the orthonormal basis or wavelet basis can be find in [26] [27].

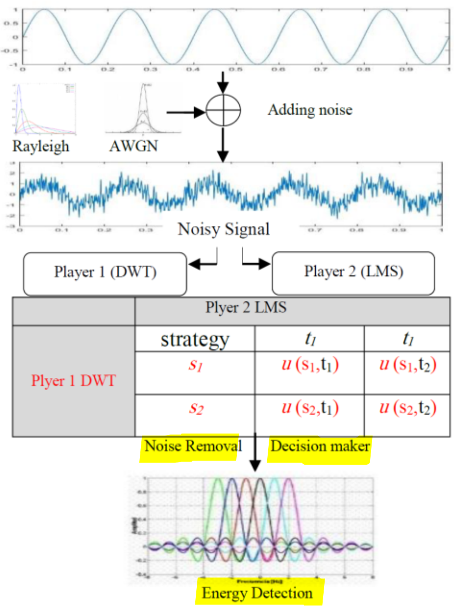

Fig. 1. The proposed game theory based signal denoising model

The second algorithm relies on adaptive filter that consists of a limited transfer function by variable parameters to regulate those parameters according to an optimization algorithm [28]. Contrary to the conventional filter design techniques, adaptive filters do not have steady filter coefficients nor prior information. Least Mean Squares (LMS) algorithms are a type of adaptive filter used to imitative a desired filter by setting the filter coefficients that allot to producing the LMS of the error signal (difference between the desired signal and the actual signal) [27].

LMS classified under the class of gradient descent algorithms, which when started with an assigned value it tracks the negative of the gradient to discovery the desired local minima of an error surface [29]. LMS algorithm has a fast convergence rate, suitable for hardware implementation because of its simplicity in structure and low complexity [30]. In the case of LMS, the guiding factor for the algorithm is the step size, which can be controls the negative descent to reach the local minima. In general, the enactment of the LMS algorithm is related by its step-size parameter. A category of optimized LMS-based algorithms (in terms of the step-size control) is suggested in which minimization of the system error as a criterion of the optimization [28]. The complete LMS algorithm can be found in [28].

C. Optimal Signal Denoising using Game Theory

The next step is to choose the best available denoising methods according to the characteristics of each signal by means of game theory as a decision making algorithm. In game theory, each denoising method is represented as a player and each player's strategies comes from the adjustment of each affective variable. Each player of the game has an associated outcome or gain, which he receives at the end of the competition (game) , and this is called payoff , which measures the satisfaction's degree of an individual player that derives from the conflicting situation [31][32]. Herein, the payoff is computed based on a package of objective function that includes SNR, MSE, BER, and complexity. Whether collaborative or not a game is, It would depend on whether the players can communicate with one another. Herein, the non-collaborative game theory is interested with the analyses of strategical choices [33] [34]. There are two ways of representing diverse components (players, actions and payoffs) of a game: strategic form, and extensive form. Here in our game we will focus on the normal form representation. Formally, a normal form of a game G is given by:

$$G = \langle N, A, \{u_i\} \rangle \tag{1}$$

where $N=\{1,2,3,\ldots\ldots n\}$ is the set of players (decision makers) in our case N=2, A_i is the action set for player i, $A = A_1 \times A_2 \times \ldots \times A_n$ is the Cartesian Product of the sets of actions existing to each player, and $\{u_i\} = \{u_1,\ldots,u_n\}$ is the set of outcome functions that each player i wishes to maximize, where $u_i : A \rightarrow \mathrm{R}$ For every player i, the utility function is an outcome of the action chosen by player i, a_i, and the actions chosen by all the players in this game but player i, denoted as a_{-i} together, a_i and a_{-i} makes up the action tuple a. An action tuple is a exclusive choice of actions by each player. From this model, stability situation known as Nash equilibria can be specified. Before describing the Nash equilibrium, we define the good response of a player as an action that make better use of her utility function for a given action tuple of the other players. Mathematically, a is a best response by player i to a_{-i} if

$$\bar{a} \in \{\arg\max u_i(a_i, a_{-i})\} \tag{2}$$

Nash Equilibrium (NE) is a game theory concept that determines the optimal solution in a non-cooperative game in which each player lacks any incentive to change his/her initial strategy. Equivalently, a NE is an action record where no singular player can benefit from unilateral deviation Formally $a^* = (a_1^*, a_2^*, a_3^*, \ldots, a_n^*)$ is the tuple actions of the NE if $u_i(a_i^*, \mathbf{a}_{-i}^*) \geq u_i(a_i^*, \mathbf{a}_{-i}^*)$ for $\forall a_i \in A_i$ and for $\forall i \in N$

Table 1 show the bimatrix for two players with its payoff in which t1 represents the player 2's strategy that concerns with the effectiveness of the step size μ on the LMS algorithm. Similarly, s_1 represents the player 1's strategy that concerns with the impact of the decomposition level on the DWT algorithm. Herein, a_{11} is the payoff value for player 1's strategy given payoff function $u_1(s_1, t_1)$ if (s_1, t_1) is chosen, and b_{11} is the payoff value for player 2's strategy given payoff function $u_2(s_1, t_1)$ if (s_1, t_1) is chosen.

TABLE I. THE BIMATRIX FOR TWO PLAYERS

	Player 2 (LMS)				
	Strategy	t_1	t_2	..	t_h
Player 1 (DWL)	s_1	(a_{11},b_{11})	(a_{12},b_{12})	⋮	(a_{1h},b_{1h})
	s_2	(a_{21},b_{21})	(a_{22},b_{22})	⋮	(a_{2h},b_{2h})
	⋮	⋮	⋮	⋮	⋮
	s_m	(a_{m1},b_{ml})	(a_{m1},b_{m1})	..	(a_{mh},b_{mh})

D. Energy Detection based Spectrum Sensing

Spectrum sensing is considered as the most important tasks performed by cognitive radio and the performance of the other functions of cognitive radio are based on the spectrum sensing. Energy detection is blind spectrum sensing technique in which no prior knowledge of details required and it's optimal when CR can't have sufficient information about primary user's waveform [33]. The energy detection model processed the signal measurements and locate the unoccupied channel by comparing the power evaluated to the predefined value stored threshold, levels; as the average of energy of signal exceeds threshold this indicates that signal is present otherwise not [33]. In general, A CR node has M consecutive sampling points in the band of a licensed user each time [34]:

$$\begin{aligned} Y[i] &= N[i], \mathrm{H0} \\ Y[i] &= h \times X[i] + N[i], \mathrm{H1} \end{aligned} \quad , \tag{3}$$

where $Y[i]$ is signal received at CR, $X[i]$ represents transmitted signal by PU and $N[i]$ are the signal and the noise and 'h' is the channel gain. The objective of energy sensing is to decide whether $H0$ or $H1$ is true by sensing the energy of the signal Y which is given by M:

$$E = \sum_{i=1}^{M} |Y[i]|^2 \tag{4}$$

As ED requires a short detection period the channel gain and primary user signal are assumed to have little changes over each detection period. So the model can be simplified as:

$$Y[i] = \begin{cases} N[i] & H0 \\ x + N[i] & H1 \end{cases} \tag{5}$$

ED is one of the threshold based detection, where the average measured energy level is compared to a threshold value. The decision is set to $H0$ when the energy level is less than the threshold value, otherwise the decision is set to $H1$. The measured power level can me modeled as a Gaussian mixed model as depicted in Fig.2 below.

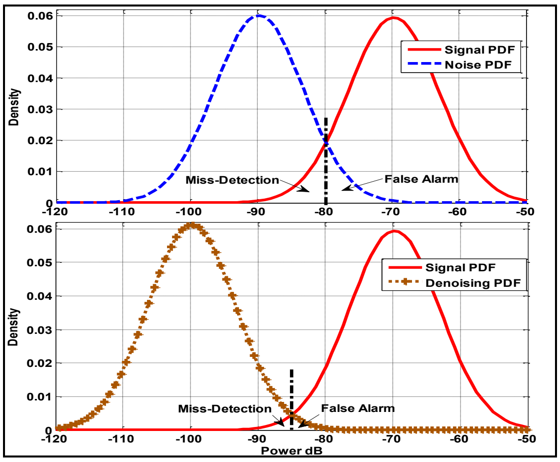

Fig. 2. Miss-Detection and False Alrm with and without denoising

The threshold level is set to the point of intersection of the two probability density functions representing the signal and noise components. It is obvious that a part of the noise fall above the threshold value, such part will contribute to the false alarm probability. Similarly, a part of the signal pdf fall below the threshold level, such part will contribute to the probability of miss-detection. It is logically accepted that reducing the noise level via denoising will reduce both error probabilities, which will lead to significant performance enhancement of the ED spectrum sensing process.

IV. EXPERIMENTAL RESULTS

Experiments were conducted on a benchmark signal dataset [35]. The database is divided into two types of signals (Wi-Fi 802.11a 5.8 GHz, 4G LTE) to cover both licensed and unlicensed frequency bands that can be used by CR systems. Wi-Fi 802.11a is available and supports high speeds data rate and has popular frequency band suitable for low cost wireless systems with less interference compared to 802.11b [24]. The LTE signal is widely used in 4G mobile devices and data terminals. Furthermore, to compare simulation experiments with others research method the system verified through The four well-known benchmark signals Blocks, Bumps, Heavy sine, and Doppler. Three degrees of noise levels (different signal to noise ratio) are added to these benchmark signals[35].

The first experiment was conducted to show how the SNR, MSE values of the suggested system depend on the increase in the numbers of strategies with different SNR noise levels in order to determine the most suitable parameters for denoising process. It can be inferred from Table 1. that higher SNR values are achieved by the suggested method in both AWGN and Rayleigh noise channels. From this table, we can see that the MSE obtained by using the game theory denoising is lower than the conventional methods, while the SNR obtained by the proposed model is higher than the other algorithm [36] which use particle swarm optimization (shown in boldface). The reassembled signals are better at reflecting the detail information of the original signals. Thus, it can be seen that the proposed model has a better ability of the noise cancelation.. One possible explanation for this improvement is that the merge of the two denoising techniques yields a solution to the issue of the various noise environments. Furthermore, the suggested system that is based on the game theory-based parameters for both wavelet and adaptive filter approach is an effective filter for noise reduction.

TABLE II. COMPARISON RESULTS OF SIGNAL DENOISING WITH OTHER ALGORITHM

Signals	Metrics	PSO	GT-based	SNR of noisy signal-dB
Blocks	MSE SNR	0.2155 13.2106	**0.2005** **14.3105**	2.0000
	MSE SNR	0.9840 18.4829	**0.9040** **19.3251**	10.0000
Bumps	MSE SNR	0.1015 14.3125	**0.0999** **16.2035**	2.0000
	MSE SNR	0.9950 21.3288	**0.9750** **23.5684**	10.0000
Heavy sine	MSE SNR	0.0705 14.8698	**0.0605** **14.2351**	2.0000
	MSE SNR	0.0619 22.4405	**0.0513** **24.5836**	10.0000
Doppler	MSE SNR	0.0907 13.5703	**0.0807** **15.5703**	2.0000
	MSE SNR	0.0896 20.6453	**0.0796** **23.9956**	10.0000

The second experiment was engaged to show how the P_d ,as a function of P_f, for the proposed model is affected with different noise (under AWGN and Rayleigh fading channels, respectively). The P_d is usually analyzed with respect to the received SNR. Figs. 3 and 4 show the comparison of the P_d for the ED technique between the suggested game theory-based denoising method and iterated DWT [18] for different noise channels. As expected the probability of detection P_d increases as the SNR increase. As is consistent with previous studies, above -6 dB, the detection probability reaches 1 for all P_f value in case of AWGN (see Fig. 3); this number varies according to the type of noise, for example in Fig. 4, in the case of Rayleigh fading noise, the signal power should be close to 0 dB to reach a very high detection rate. It is well understood when the power of received signal gets higher, probability of detection becomes much easier. In general, achieving 0.01 false alarm probability and 0.99 detection probability needs a very high SNR.

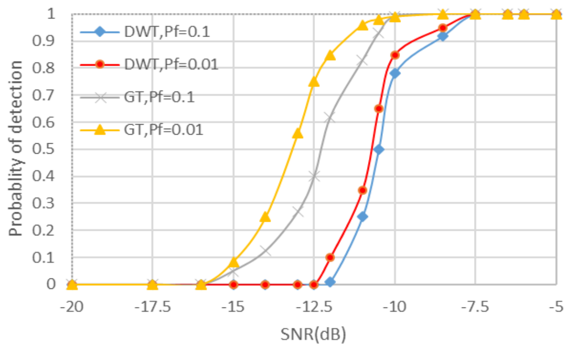

Fig. 3. P_d under AWGN channels

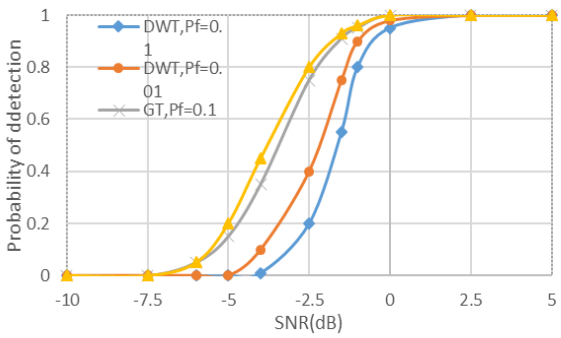

Fig. 4. P_d under Rayleigh fading channels.

V. CONCLUSION AND FUTURE WORK

In this paper, GTD has been used for signal denoising to enhance the ED performance in case of signal denoising before detection. GTD has been explained as a competition manner between LMS and DWT. The simulation results demonstrate the P_d versus the SNR for various values of the Pf under AWGN and Rayleigh fading channels. In all these results, GT has exceeded DWT in detection of the presence or absence of the PU signal at the SU receiver. Furthermore, the complexity for the GT is less time and less complexity of the iterated DWT by choosing the strategy with the higher payoff contrary DWT tries with different parameters in goal to get the optimal solution. This reduction leads to reducing the total system complexity of the SU. The idea of the GT is that each algorithm chooses the most appropriate strategy in terms of time and signal quality to reach the detection of the PU as soon as possible. It is possible in the future to add more players to reach better results as well as apply the proposed system in real time.

REFERENCES

[1] Y. Liang, K. Chen, G. Li and P. Mahonen, "Cognitive radio networking and communications: an overview," IEEE Transactions on Vehicular Technology, Vol. 60, No. 7, pp. 3386-3407, 2011.

[2] T. Mushtaq, M. Khan, and R. Khan, " Cognitive Radios and Cognitive Networks: a Short Introduction ", International Journal of Basic & Applied Scientific Research, Vol. 3, Issue, 4, pp. 262-268, 2013.

[3] A. Quadri, M. Manesh, and N. Kabouch, " De-noising Signals in Cognitive Radio Systems using an Evolutionary Algorithm based Adaptive Filter", Proceedings of the International Conference on Ubiquitous Computing, Electronics & Mobile Communication (UEMCON), pp.1-6, 20-22 October, USA, 2016.

[4] A. Quadri, "A Review of Noise Cancellation Techniques for Cognitive Radio", Proceedings of the International Conference on Electrical Engineering and Systems Science - Signal Processing, pp.1-10, 20-22 October, USA, 2018.

[5] Y. Jiao, R. Cheung, W. Chow, and M. Mok, "A Novel Gradient Adaptive Step Size LMS Algorithm with Dual Adaptive Filters," Proceedings of International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 4803-4806, 3-7 July, Japan, 2013.

[6] G, Pankaj, and P. Beniwal. "Adaptive Filters Algorithms: A Performance Comparison." International Journal of Engineering Research and General Science, Vol. 3, Issue, 4, pp. 2091-2730, 2015.

[7] B. Mohamed, M. Baade, and M. Batouche, "A Novel Approach for Image DE noising based on Evolutionary Game Theory," Proceedings of IEEE International Conference on Image Processing Theory Tools and Applications, pp. 1-6, 14-17 October, France, 2014.

[8] C. Jean, and B. Jabbari, "on Wireless Game-Theoretic Power Control with Successive Interference Cancellation," Proceedings of the IEEE International on Vehicular Technology, pp. 1-5, Canada, 2006.

[9] S. Boroujeny, and M. Eshghi, "Efficient Adaptive Noise Cancellation using Genetic Optimization," Proceedings of the IEEE International Conference on Signal Processing, pp. 2596-2599, 24-28 Oct, Beijing, 2010.

[10] Z. Xun, and X. Jianchun "A Particle Swarm Optimization Technique-Based Parametric Wavelet Thresholding Function for Signal Denoising", Circuits Systems and Signal Processing, Vol. 36, No. 1, pp. 247-269, 2017.

[11] Wu. Zhuang, "Signal De-noising method based on particle swarm algorithm and Wavelet transform", Tehnički vjesnik Vol. 21, No. 5, pp. 1001-1008, 2014.

[12] N. Omidvar, and B. H. Khalaj, "A Game Theoretic Approach for Power Allocation in The Downlink of Cognitive Radio Networks", Proceedings of the IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, pp. 158-1, 62, 10-11 June, Japan, 2011.

[13] K. Erkan, M. Erbas, and E. Ersen, "An Integrated Approach Based on Game Theory and Geographical Information Systems to Solve Decision Problems." Applied Mathematics and Computation, Vol. 308, pp. 105-114, 2017.

[14] H. Wang, Y. Xu, X. Su, and J. Wang, "Cooperative Spectrum Sensing with Wavelet De-noising in Cognitive Radio" Proceedings of IEEE International Conference on Vehicular Technology, pp. 1-5, 16-19 May, Taipei, 2010.

[15] G. Padmavathi, and S. Shanmugavel. "An Enhanced Cooperative Spectrum Sensing with Wavelet Denoising and Softened Hard Decision for Cognitive Radio Networks", International Journal of Future Generation Communication and Networking, Vol. 7, No. 6, pp. 81-90, 2014.

[16] Li. Xiaoyan, H. Fei · Z, Hailin, S. Chao, "Two-Branch Wavelet Denoising for Accurate Spectrum Sensing in Cognitive Radios", Telecommunication Systems, Vol. 57, No. 1, pp. 81-90, 2014.

[17] Martínez, M. Daniela, and G. Angel, "Reducing the effects of the noise uncertainty in energy detectors for cognitive radio networks." International Journal of Communication Systems, Vol. 30, No.1, pp. 1-17, 2017.

[18] H. Al-Hmood and H. S. Al-Raweshidy, "Signal denoising using hybrid slantlet transform based energy detector in cognitive radios", Proceedings of International Conference on Wireless Days, pp. 1-3, 13-15 Nov, Valencia, 2013,

[19] A.Iman "Hybrid Transform Based Denoising with Block Thresholding", Journal Of The College Of Education For Women, Vol. 23, No. 4, pp. 1279-1290, 2012.

[20] B. van, W. Jan, S. Roel, and H. Cornelis, "Removing non-stationary noise in spectrum sensing using matrix factorization." EURASIP journal on advances in signal processing, Vol. 1, No. 72, 2013.

[21] K. Devarajan "Nonnegative Matrix Factorization: An Analytical and Interpretive Tool in Computational Biology". PLoS Comput Biol Vol. 4, No. 7, 2008.

[22] H. Farag, and E. Mohamed. "Soft decision cooperative spectrum sensing with noise uncertainty reduction", Pervasive and Mobile Computing, Vol. 35, pp. 146-164, 2017.

[23] Eltholth, Ashraf A. "Modified Cyclostationarity Feature Detection for Asynchronous PU Occurrence in Cognitive Radio Systems.", International Journal of Engineering and Applied Sciences, Vol.4, No. 8, pp.1-5, 2017.

[24] R. Ruslan and T. C. Wan, "Cognitive radio-based power adjustment for Wi-Fi", Proceedings of TENCON 2009 - 2009 IEEE Region 10 Conference, 23-26 Jan, pp. 1-5, Singapore, 2009.

[25] P. Karunakaran, T. Wagner, A. Scherb and W. Gerstacker, "On simultaneous sensing and reception for cognitive LTE-A systems", Proceedings of International Conference on Cognitive Cellular Systems, pp. 1-5, 2-4 Sept, Germany, 2014.

[26] Kanithi, Anil Kumar, and S. Meher. "Study of Spatial and Transform Domain Filters for Efficient Noise Reduction." Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela, India, 2011.

[27] H. Lin,S. Lianga, Y. Hob, and YH. Linb. "Discrete-wavelet-transform-based noise removal and feature extraction for ECG signals", Innovation and Research in Biomedical Engineering, Vol. 35, No.6, pp. 351-361, 2014.

[28] D. Shubhra, and D. Nagaria. "LMS Adaptive Filters for Noise Cancellation: A Review", International Journal of Electrical and Computer Engineering, Vol. 7, No.5, pp. 2520-2529, 2017.

[29] M. Arif, I. Naseem, M. Moinuddin, S. Khan, and M. Ammar, "Adaptive Noise Cancellation Using Q-LMS", Proceeding of International Conference on Innovations in Electrical Engineering and Computational Technologies, pp. 1-4, 5-7 April, Pakistan, 2017.

[30] Y. Jiao, R. Cheung, W. Chow, and M. Mok, "A Novel Gradient Adaptive Step Size LMS Algorithm with Dual Adaptive Filters," Proceedings of International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 4803-4806, 3-7 July, Japan, 2013.

[31] L. Banjanovic-Mehmedovic, E. Halilovic, and I. Bosankic, "Autonomous Vehicle-to-Vehicle (V2V) Decision Making in Roundabout using Game Theory," International Journal of Advanced Computer Science and Applications, Vol. 7, No. 8, pp. 292-298, 2016.

[32] J. Sheu, Z. Wu, C. Ma, and R. Jagadeesha, "Interference-Aware Channel Allocation Algorithm with Game Theoretic Approach for Cognitive Radio Networks," Proceedings of the IEEE International Parallel and Distributed Systems, pp. 41-46, 16-19 December, Taiwan, 2014.

[33] Q. Zhu, H. Tembine, and T. Basar, "Evolutionary Games for Hybrid Additive White Gaussian Noise Multiple Access Control," Proceedings of the international Conference on Global Telecommunications, pp. 1-6, 30 November-4 December, USA, 2009.

[34] V. Pai, A. Prabhu, and A. Menon, "Game Theoretic Optimization of Spectrum Allocation in Cognitive Radio," Proceedings of International Conference on Computing Communication Control and automation, pp. 1-5, 12-13 August, India, 2016.

[35] Z. Xun, and X. Jianchun, "A Particle Swarm Optimization Technique-based Parametric Wavelet Thresholding Function for Signal Denoising", Circuits Systems and Signal Processing, Vol. 36, No. 1, pp. 247-269, 2017.