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NEW TECHNOLOGY FOR COGNITIVE RADIO A METHOD FOR DYNAMIC SPECTRUM MANAGEMENT

Józef Pawelec and Marek Suchański[1]
Military Communications Institute, Zegrze - Warsaw str. 22A, Poland

Abstract::- ***A brief theoretical analysis of the spectrum sensing via energy detection for Cognitive Radio is done. A special case of one spot multiple-time cumulative sensing under Rayleigh fading environment is considered in detail and simulated. The obtained results are as follows: probabilities of detection P_d>0.9, Pm=Pf=0.1, signal-to-noise ratio SNR≤0 dB, number of samples M≈1000.***

Keyword – Cognitive Radio, multiple energy detection, cumulative sensing of spectrum, simulations

I. INTRODUCTION

The spectrum sensing is used for dynamic frequency management in Cognitive Radio [1-6]. There are many techniques and objects of sensing. The most popular is energy detection. This process runs as follows: a tested signal is first transferred through the low-pass receiving filter, next it is squared to get the energy value and the result is finally compared with some threshold λ. If the measured value exceeds λ, the decision is: *signal present*, otherwise the decision is *signal absent* and the frequency is then considered free for a new assignment to some secondary user.

Usually multiple energy detection (MED) is used. It exploits many signal samples taken in different time moments and/or different spots to increase the accuracy. There is, however, a limit on sampling time, e.g. one second [3]. So we decided to group samples into the overlapping series: 1,2,…,N, next 2,3,…,N+1, next 3,4,…,N+2 and so on. In the sequel the total energies of these groups are calculated and used instead of individual samples' energies. The goal of the new method is to improve the effectiveness and speed of the dynamic spectrum management in real fading environment.

The rest of this paper contains the following sections: an outline of the multiple-time detection theory (sec. 2), the detailed description of the cumulative sensing method and its simulation (sec. 3) and the discussion of the obtained results (sec.4).

In conclusion the authors claim that it is possible to detect the Rayleigh fading signal down to the *SNR* =0 dB with probabilities of falls/miss alarms $P_f=P_m=10^{-1}$ for the total number of samples of no more than 1000.

II. AN OUTLINE OF THE THEORY

Usually the following formulae are used in multiple energy detection (MED) [5]

$$\begin{aligned} r_1(t) &= \mathrm{Re}\{[hS_{LP}(t)+n_{LP}(t)]\exp(j2\pi f_c t\} - hyp.\, H_1 \\ r_2(t) &= \mathrm{Re}\{n_{LP}(t)\exp(j2\pi f_c t)\} - hyp.\, H_0 \end{aligned} \qquad (1)$$

where $h=\alpha e^{j\theta}$ - input/output function of the slowly variable channel, α - its module, θ - its phase; S_{LP} – low-path signal, $S_{LP}(t)=S_c(t)+ jS_s(t)$; n_{LP}- additive low-path noise of the energy N_0 $n=n_1+jn_2$, f_c – carrier frequency.

The signal-to-noise ratio is defined as follows

$$\bar{\gamma} = \alpha^2 E_s / N_0 \qquad (2)$$

where E_s – input energy of a signal.

The process of detection runs as follows. A received signal *r(t)* is passed through the low-pass filter (rectangular). Next its output is squared and the result is integrated over some period *T*. The obtained products are used to form a new value *y*, which is used as a statistical test for the decision: the signal S_{LP} is present in *r(t)* or not

$$y = \frac{2}{N_0}\int_0^T r^2(t)dt = \frac{1}{N_0 W}\begin{bmatrix} \sum_{i=1}^{N/2}(\alpha_c S_{ci} - \alpha_s S_{si} + n_{ci})^2 + \\ \sum_{i=1}^{N/2}(\alpha_c S_{ci} + \alpha_s S_{si} + n_{si})^2 \end{bmatrix} \qquad (3)$$

It has been shown that probability density function *f(y)* is expressed as follows [5]

$$f(y) = \begin{pmatrix} \frac{1}{\sigma^N 2^{N/2}\Gamma(N/2)} y^{N/2-1} e^{-y/2\sigma} & H_0 \\ \frac{1}{2\sigma^2}\left(\frac{y}{\alpha\gamma}\right)^{(N-2)/4} e^{-\frac{\alpha\gamma+y}{2\sigma^2}} I_{N/2-1}\left(\frac{\sqrt{\varepsilon\gamma y}}{\sigma^2}\right) & H_1 \end{pmatrix} \qquad (4)$$

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E-mail addresses: j.pawelec, m.suchanski@wil.waw.pl

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The eq.(4) expresses the well known χ-square distributions, a central one for hypothesis H_0 and $\mu=\alpha\gamma$ displaced for H_1. $\Gamma(\cdot)$ - gamma function; $I_{N/2-1}(\cdot)$ – Bessel function of the first kind and the order $\frac{N}{2}$-1.

The probabilities of false and missed alarms are then as follows

$$P_f=\frac{\Gamma(N/2,\lambda/2\sigma^2)}{\Gamma(N/2)},\ P_m=\gamma\left(N,\frac{\lambda}{\sigma_w^2+\sigma_s^2}\right) \qquad (5a,b)$$

where Γ(s) is gamma function, $\Gamma(s,x)$ - an incomplete upper gamma function, γ(s,x) - incomplete lower gamma function, Fig. 1-3, respectively

$$\Gamma(s)=\int_0^\infty t^{s-1}e^{-t}dt$$

$$\Gamma(s,x)=\int_x^\infty t^{s-1}e^{-t}dt\ ,\ \gamma(s,x)=\int_0^x t^{s-1}e^{-t}dt \qquad (6)$$

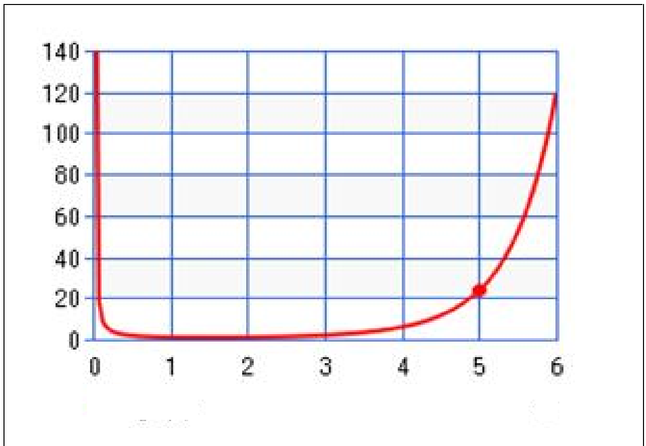

Fig.1. The gamma function Γ(s

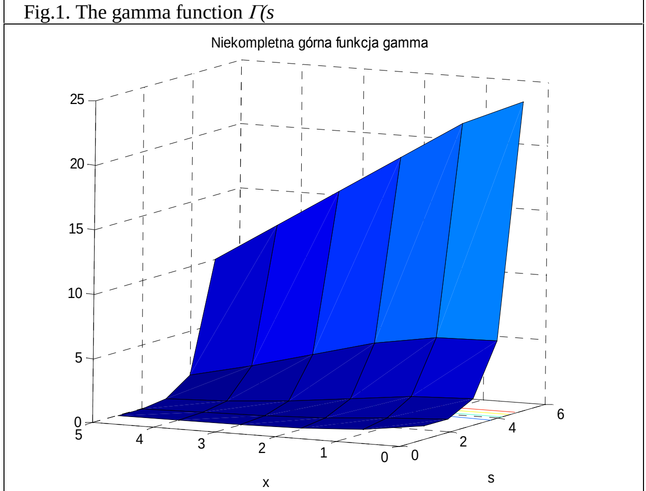

Fig.2. The incomplete upper gamma function $\Gamma(s,x)$

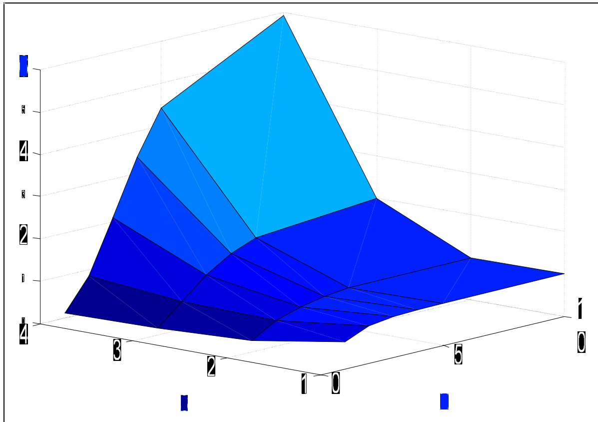

Fig.3. The incomplete lower gamma function $\gamma(s,x)$

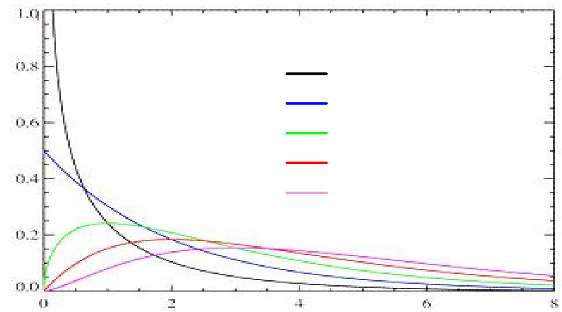

Fig.4. The chi-square distribution *f(y)* for the different degrees of freedom *s*

We can observe from Fig.4 that the chi-square distribution for s>>1 approaches the Gaussian distribution. Hence some coarse evaluation of the gain of multi-point detection can be done using this distribution [1-3].

It is also possible to get the false alarm data from the eq.(5a)[1]. Namely, if s=1 and $x=\lambda/2\sigma^2=1$, the $\Gamma(s,x)$=0.37 and $\Gamma(s)$=1, hence $P_f=0.37$. If the variable *x* is still moderate, but s=*N/2*>>1 the function $\Gamma(s)$, Fig.1, increases very sharply, so the probability of false alarm $P_f \rightarrow 0$. This explains the positive role of the multipoint detection.

The above considerations, however, do not take into account the fading phenomenon of the useful signal and the sensing method peculiarity. So, we turned to the simulation.

III. THE SIMULATION PROCESS

The general formula of fading is as follows

$$f(\gamma)=\frac{1}{\Gamma(m)}\left(\frac{m}{\gamma}\right)^m\gamma^{m-1}\exp\left(-\frac{m}{\bar{\gamma}}\gamma\right) \quad (7)$$

where γ - instantaneous signal-to-noise ratio, $\bar{\gamma}$ - mean γ, *m* – a parameter.

[1] The precise calculators are easily available in www base

We will further focus on the strongest Rayleigh fading for *m=1*. The model of such channel is defined in [7-8]. It is based on the Doppler shift and uses the raised cosine function and the random changes of the signal phase, Fig.5. This model is highly advanced and consumes much time, so we further use a simpler one and in consequence the more general. It takes into account the energy relations only. The fundamental equation is as follows

$$s(k) = n(k) * conj\,[n(k)] \qquad (8)$$

where $n(k)$ – a normal variable, k -discrete time, $k=1,2,\ldots,N$, *conj* – conjugation operation.

An example of 10000 points distribution is shown in Fig.6. We can see that it is a typical exponential function attributed to the Rayleigh fading law [6].

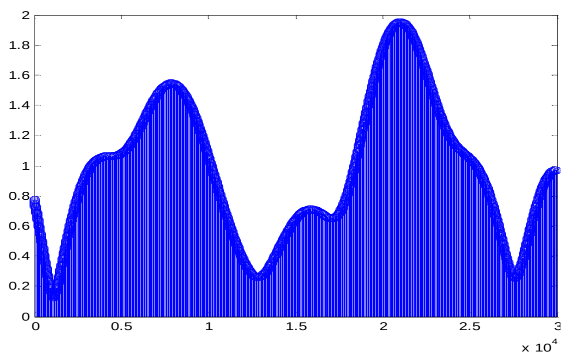

Fig.5.The envelope of the simulated BPSK signal

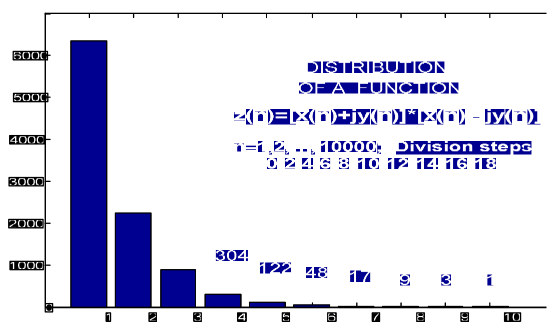

Fig.6. The distribution of signal magnitudes

As we already said (sec. II) the first step in detection process is filtration. Usually the rectangular (Chebyshev) filter is used. We will apply the more real low-path filters of the Z-transforms as follows:

$$H_1(z) = \frac{1}{z^{-2} - 1.5z^{-1} + 0.6} \quad \text{or}$$

$$H_2(z) = \frac{0.1}{z^{-4} - 3z^{-3} + 3.45z^{-2} - 1.8z^{-1} + 0.36} \qquad (9a,b)$$

The process of detection is illustrated in Fig.9. In the left arm of the scheme the series of the random signal s(k) is generated due to eq. (8) and in the right arm – the series of noise, n(k). The n(k) samples out of the filter present the complex variables, so that, their energy quantities are obtained through the conjugation operation.

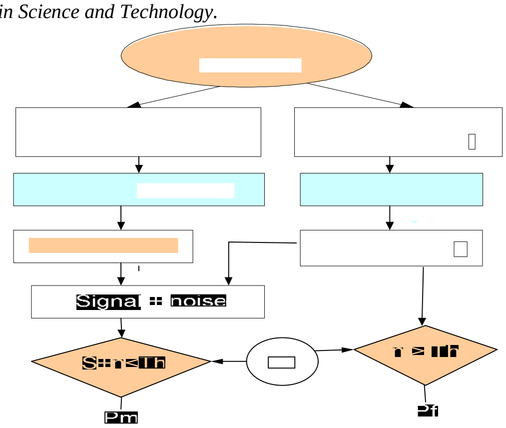

Fig.5. The algorithm of detection process

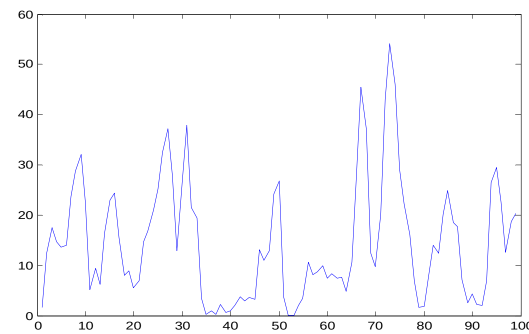

Fig.7. The power samples of noise series n*conj(n)

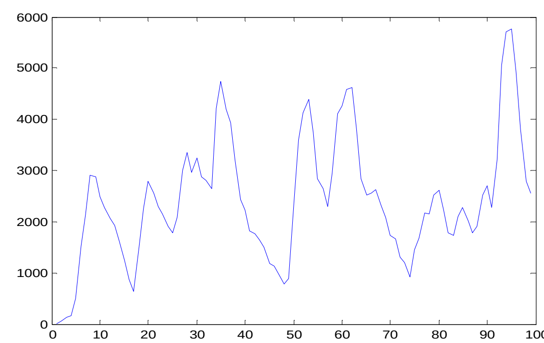

Fig.8. The signal series out of filter H_1

IV. DISCUSSION OF RESULTS

The obtained results of detection are shown in the Tab. I The main data are the numbers of faults (*f* and *m*) within the examined groups of samples and values of SNR. The samples were divided as follows: for the lowest subgroup of $M=8$ we have chosen: $1,2,3,\ldots,M=8;\ 2,3,4,\ldots,M+1;\ 3,4,5,\ldots,M+2;\ \ldots;1000,\ldots,M+1000$. For the highest subgroup of $M=96$ we have chosen: $1,2,3,\ldots,M=96,\ldots,M+1000$.

The essential parameters of any detection system are: the signal-to-noise ratio SNR [dB], the threshold *Th* and the probabilities P_f, P_m. In this paper the threshold *Th* presents the magnitude of the power expressed in the same unities as samples, e.g. $Th=(n+s)/4$, where *n* - a mean power of noise and (within a group), *s* - a mean signal power.

Tab.I. The threshold limits vs. SNR and M size

Group size M	Threshold Th	Gain in SNR
M = 1	32 – 51	0
M = 32	38 – 65	15
M = 96	56 – 78	20

It is seen from the table I, that the higher the size of group *M*, the higher the SNR gain at the same limit of false and missed alarm $P_{f,m}=0.1$. It should be noted, however, that the detection threshold *Th* in each experiment was adjusted to the signal/noise ratio. The numbers *32/51, 38/65...* mean the allowable changes of the threshold *Th* assuming the false and missed alarms are equal or less 0.1

It should be noted, however, that presented model is somewhat simplified. The main reservation concerns the Rayleigh fading processes. The rigorous approaches usually use more advanced complex value models [8]. Moreover the threshold of detection *Th* is still far from practical application

Nevertheless, the idea itself of accumulation the data seems to be highly valuable. It allows to cut diametrically the numbers of samples from millions to thousands. This way the international standards of sensing time can be met [3]. The more advanced and practical approach is being prepared [8-9]

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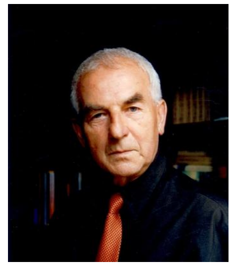

Prof. J. Pawelec received all his scientific degrees from Military Academy of Technology, faculty of Electronics, Warsaw, in 1975, -82 and 2003. His main areas of interests are: wireless communications, signal processing, informatics and compatibility.

He is currently with Military *Communication Institute* and *European University of Informatics and Economy.*

His main books are: *Space Control and Communications* and *Radio-communications*. He published papers in *IEEE Com. Magazine, Int. J. Sat. Com. & Networking,* also in *Journal of Communications*. He took part in many domestic and some international projects on communications.

M.Suchanski (Ph.D, D.Sc) received all his scientific degrees from Military Academy of Technology, faculty of Electronics, Warsaw, Poland in 1978 and 2013. His main areas of interests are: wireless communications, propagation of waves and spectrum management.

He currently works as a professor for Military Communication Institute. His main book is Spectrum Management in Milittary Communications Networks (in Polish). He published papers in many communications magazines and domestic and international conferences.