Performance of Hybrid Sensing Method in Multipath Fading Environment

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***Abstract*—The article presents an analysis of the efficiency of the hybrid sensing method for Rayleigh and *m*-Nakagami fading channels. The proposed hybrid detector (HD) takes advantage of the energy detection (ED) and a method based on the Covariance Absolute Value (CAV). The paper describes the model of the system and presents the simulation results for OFDM signal (Orthogonal Frequency Division Multiplexing) of WiMAX system. The simulation results were presented for the AWGN channel – the case currently considered in the literature, and then repeated for the environment with Rayleigh fading as well as mild and severe *m*-Nakagami fading.**

Keywords— hybrid detector; multipath fading; Rayleigh fading; m-Nakagami fading; OFDM; WiMAX.

I. INTRODUCTION

Cognitive wireless systems are the implementation of the paradigm of the Dynamic Spectrum Access that increases the efficiency of spectrum use and makes the access to it more flexible. Potential capabilities of the cognitive radio (CR), such as the wide use of adaptive techniques, the recognition of the radio environment, the use of learning methods and intelligent decision making, make CR technology the leader in the development of wireless networks [1].

One of the basic functionalities of the CR is gathering information about the radio environment, i.e. building the so-called spectrum awareness of each element of the network. One of the methods of obtaining information about the state of spectrum usage considered in the literature is sensing [2] – recognition of the electromagnetic environment. It involves monitoring broad spectrum bands and detecting unused spectrum parts (spectrum holes / white spaces) as well as detecting primary (licensed) users (PU), especially in ad-hoc radio networks.

The problem of sensing is the subject of extensive theoretical analysis. Numerous spectrum scanning techniques have been proposed for cognitive radio systems, which have both advantages and disadvantages. For this reason the literature dealing with the methods of spectrum sensing optimization in order to increase their efficiency proposes detectors with hybrid architecture, which combines advantages of various detection methods [3][4][5][6].

In such architecture there is usually a combination of a basic method using an energy detector with one or several more complex detection methods, such as detection using a matched filter, detection of cyclostationary features, wavelet detection, eigenvalue-based detection or covariance-based detection. This allows to increase detection speed while ensuring high reliability and detection sensitivity.

The detection of signals is strictly dependent on the propagation conditions in a specific environment. In wireless communication, transmitted signals are subject to random variation, which is caused by the multiplicative and additive interference and delays in radio channels [6]. For this reason, the phenomena occurring in the radio channels cannot be missing in the research on the efficiency of hybrid detectors.

However, the results of HD research presented in the literature present their advantages when compared to autonomous methods of sensing only in AWGN channels and for an ideal scenario in which the uncertainty of spectral density of noise power estimation is not taken into account. Another factor missing in the current research is the attenuation of signals caused by multi-path propagation, as a result of which only a part of the energy emitted by the transmitter reaches the receiver (the detector).

The analysis of HD efficiency in environment with uncertainty associated with the spectral density of noise power estimation has been presented in [6], where it can be seen that main gain of using HD is reduction of sensing time. However, this paper presents the analysis of HD efficiency in multipath fading environment. Further on in the paper, Rayleigh fading and *m*-Nakagami fading are briefly characterized. Next, the description of the used HD is presented and a system model for which simulations have been carried out is characterized. In the remaining part of the paper there is a presentation of results of the research for the WiMAX system for several cases: the AWGN channel considered in the literature so far, Rayleigh fading as well as mild and severe *m*-Nakagami fading ($m = 3$ and $m = 0.65$). The obtained results indicate that making the scenario more realistic by introducing multipath fading worsens the efficiency of HD only in extreme cases.

II. CHANNEL WITH MULTIPATH FADING

The fading is treated as random signal attenuation caused by multi-path propagation (scattering, refraction or reflection of signals from surrounding objects).

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In the case of fading, the low power level of the received signal does not necessarily mean that the licensed system is outside of the range of the secondary users' (SU) system interference. For this reason, in environment with fading, it is difficult to carry out the sensing, because the SU must be able to distinguish between the so-called spectrum holes, in which there is no PU signal, from severe fades in which the detection of a PU signal is difficult. Therefore, the SU may not be able to make a sufficiently reliable decision about the presence or absence of a PU signal.

The exact analytical description of the fading phenomenon is either unknown or too complicated. However, relatively simple and accurate statistical models have been developed for the channels with fades [8][9], which provide scaling of the depth of fades and their duration. The use of individual models depends on the specific propagation environment and the adopted communication scenario.

The most popular and relatively easy to implement is the channel model with Rayleigh fading [10], whose characteristics of the error distribution [11] map the real VHF channels well. The models of Rice's and *m*-Nakagami's fading are equally often used [12].

III. Hybrid Detector

The proposed HD is a two-phase detector combining advantages of both detection methods used in this approach: ED and CAV. The scheme of the detector is shown in Fig. 1.

For each channel, the presence of PU is firstly determined in the first detection phase in which ED is used. Although this method is sensitive to the uncertainty of noise, its obvious advantage is the speed of detection and accuracy at high SNR values. Therefore, the decision about a PU signal presence will be taken only in unquestionable situations – the energy of the received signal ($T_1 = T_{ED}$) will be higher than the first phase detection threshold ($\lambda_1 = \lambda_{ED}$) calculated for the assumed probability of a false alarm (P_{fa}).

If the decision cannot be made using ED, CAV is used in the second phase of hybrid detection as a more accurate method. The decision about a PU signal presence is taken when decision statistic ($T_2 = T_{CAV}$) is greater than the second phase threshold ($\lambda_2 = \lambda_{CAV}$). Otherwise, a decision about a PU signal absence is made.

Detailed considerations relating to the autonomous detection methods used in HD and corresponding theoretical assumptions and formulas are presented in [6].

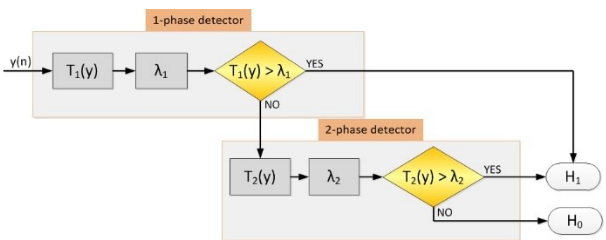

Fig. 1. Scheme of hybrid detector.

IV. System Model

The requirements that the cognitive radio must fulfill in sensing the primary user's signals are directly connected with the cognitive system scenario. In the paper the WiMAX (IEEE 802.16-2004 [13]) as a licensed system has been assumed with the parameters specified in Table I. The following detection parameters have also been assumed:

- probability of a detection $P_d = 0.9$;
- probability of a false alarm $P_{fa} = 0.1$.

TABLE I. PARAMETERS OF THE LICENSED SYSTEM

Parameter	Value
Bandwidth	3.5 MHz
OFDM symbol duration	80 µs
OFDM useful symbol duration	64 µs
Cyclic Prefix ratio	1/4
FFT size	256

CR systems using hybrid detection methods have been analyzed in an urbanized environment in the conditions of movement of network nodes. For such a scenario, the Rayleigh fading model is the one most commonly used in the literature.

In addition, the analysis has been carried out for the fading described by the *m*-Nakagami model, which ensures good mapping of channels in the urbanized environment. The method of fading generation proposed in [14] has been used to generate the *m*-Nakagami fading. The tests included mild and severe *m*-Nakagami fading ($m = 3$ and $m = 0.65$, respectively).

The movement of objects is revealed in the Doppler spread (F_D), which together with the symbol duration (T_S) of an emission characterizes the dynamics of the radio channel changes. The product of the values above($F_D T_S$), is called the normalized fading rate [15].

The maximum Doppler shift depends on the speed of movement of the object and the frequency of the system's operation. The potential speed of moving objects, which is taken into account in designing wireless systems, can reach even 500 km/h. Still, such speed is unrealistic in most applications. However, with the assumption that the maximum Doppler shift can be (due to the movement of other objects) twice as large as it results from the speed of movement of the single object under analysis [10], a more real value of 300 km/h has been assumed.

The second factor defining the fading rate is the duration of the symbol. In this respect, each system is characterized by its own parameters. In the case of the WiMAX system, the duration of the OFDM symbol including the guard interval is $T_S = 80\mu s$.

Table II presents some examples of the normalized fading rate values for the speed of movement of the object at 10 km/h, 50 km/h and 300 km/h.

TABLE II. PARAMETERS OF THE LICENSED SYSTEM

Speed [km/h]	Normalized fading rate $F_D T_S$
10	0.0008
50	0.0086
300	0.055

Fig. 2 and Fig. 3 show exemplary envelope of fading signals for a maximum speed of 300 km/h and 50 km/h (*Ns* – number of samples).

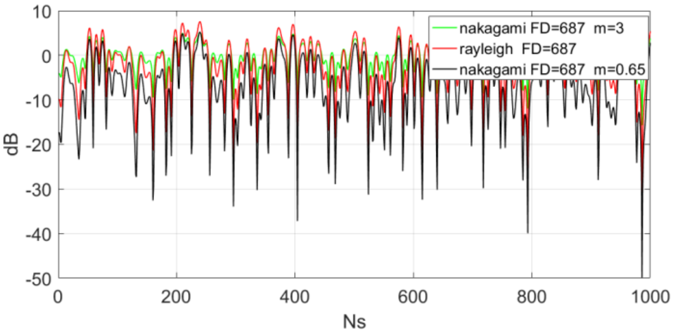

Fig. 2. Exemplary envelope of fading signals for $F_D = 687$ ($v = 300$ km/h).

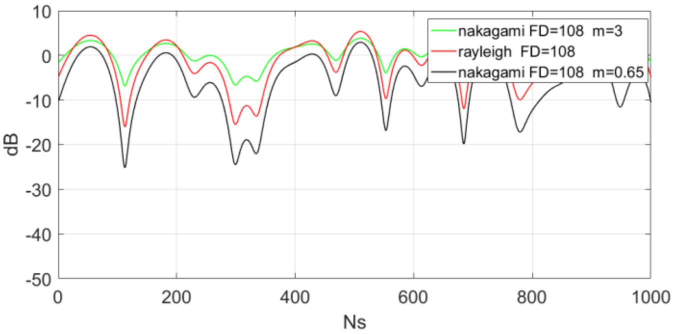

Fig. 3. Exemplary envelope of fading signals for $F_D = 108$ ($v = 50$ km/h).

V. Simulation Results

The purpose of the simulations was to check the influence of multi-path fading on HD efficiency. For this purpose, tests of the proposed HD were conducted in additive white Gaussian noise (AWGN) environment. Then, the HD efficiency was tested for channels with Rayleigh and *m*-Nakagami fading. In order to make an accurate comparison of the case with fading to the case without fading (considering that the fading has an influence on the signal level), the noise of the same spectral power density (as in the case of no fading) was added to the generated signal.

To determine the probability of detection (P_d) in a SNR function with the assumed number of samples (*N* – number of OFDM signal symbols), a false alarm probability of 10% was assumed ($P_{fa} = 0.1$).

Firstly, the impact of the assumed maximum Doppler shift was checked, as shown in Fig. 4. The obtained results show that the reduction in HD efficiency occurs in the case of severe *m*-Nakagami fading only. For $N = 2$, HD reaches P_d of 90% for $SNR = -9$ dB in AWGN case, and for $SNR = -5.5$ dB in $m = 0.65$ case. For the length of the received signal $N = 50$ it is $SNR = -16.5$ dB for AWGN and $SNR = -13$ dB for $m = 0.65$. This means that in the case of severe fading the HD efficiency is worse by 3.5 dB compared to AWGN. On the other hand, both mild *m*-Nakagami fading ($m = 3$) as well as Rayleigh's fading (regardless of the length of the received signal) have practically no influence on the probability of signal detection.

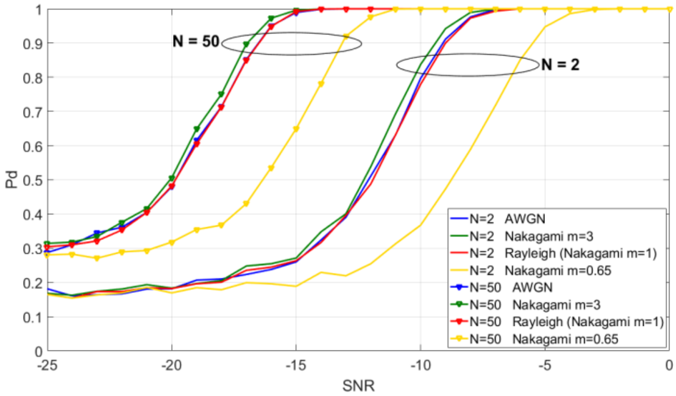

Fig. 4. The probability of detection in a SNR function for $F_D T_S = 0.055$ ($v = 300$ km/h)

Fig. 5 shows the comparison of the HD efficiency for AWGN and cases with fading when the Doppler shift is much smaller ($F_D = 108$). As in the previous case, the mild *m*-Nakagami fading and Rayleigh fading almost do not affect HD performance. However, HD efficiency in the case of severe *m*-Nakagami fading ($m = 0.65$) for $P_d = 0.9$ is worse by {4; 3} dB for $N = \{2; 50\}$ (respectively) in relation to AWGN.

Fig. 6 shows the simulation results for a quasi-static case in which the Doppler shift is small ($F_D = 10$). It can be noticed that for a sufficiently long signal ($N = 50$), the influence of mild *m*-Nakagami fading ($m = 3$) and Rayleigh fading is insignificant, just like in the previous cases. While for $m = 0.65$ (severe *m*-Nakagami fading) HD efficiency for $P_d = 0.9$ is lower by 3.5 dB compared to the AWGN.

Only in the case of a short signal ($N = 2$), in addition to the deterioration of HD efficiency due to severe fading ($m = 0.65$), a significant effect of Rayleigh fading can also be seen. HD reaches $P_d = 0.9$ with $SNR = -9$ dB for AWGN and with $SNR = -5.5$ dB for Rayleigh fading and with $SNR = -3.5$ dB for $m = 0.65$. This means that in the case of severe and Rayleigh fades, the HD efficiency in relation to AWGN is worse by {5.5; 3.5} dB, respectively.

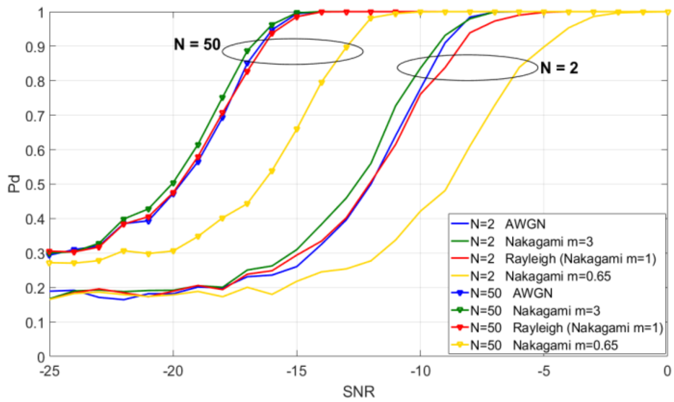

Fig. 5. The probability of detection in a SNR function for $F_D T_S = 0.00864$ ($v = 50$ km/h)

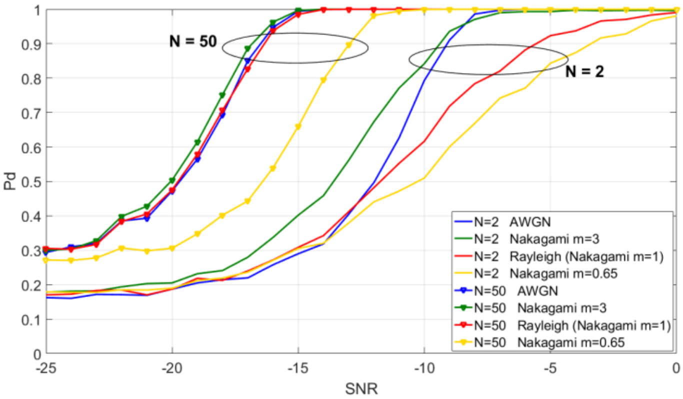

Fig. 6. The probability of detection in a SNR function for $F_D T_S = 0.0008$ ($v = 5$ km/h)

In order to check the impact of multipath fading on HD reliability (probability of false alarm), the ROC (Receiver Operating Characteristic) curves were determined – Fig. 7.

For the maximum Doppler shift ($F_D = 687$) it can be seen that like in the previous cases (P_d in SNR function), the effect of mild *m*-Nakagami fading ($m = 3$) and Rayleigh fading on the probability of false alarm is insignificant. However, for $m = 0.65$ (severe *m*-Nakagami fading) the reliability of HD in relation to AWGN is worse. For $m = 0.65$ HD reaches P_d of 90% for P_{fa} increased by 6% as compared to AWGN.

VI. Conclusion

The paper presents the results of the analysis of the efficiency of the hybrid sensing technique, in which in the first phase the received signal is subjected to energy detection, which ensures fast detection of strong signals. In the case of weak signals, when the detected signal power level does not allow for a reliable decision about the presence of the priority user, the CAV method is additionally used.

The results of HD simulation tests for the OFDM signal of the WiMAX system are presented for the AWGN channel - the case which is most often considered in the literature. In addition, the tests were repeated for the environment with Rayleigh fading as well as mild and severe *m*-Nakagami fading ($m = 3$ and $m = 0.65$).

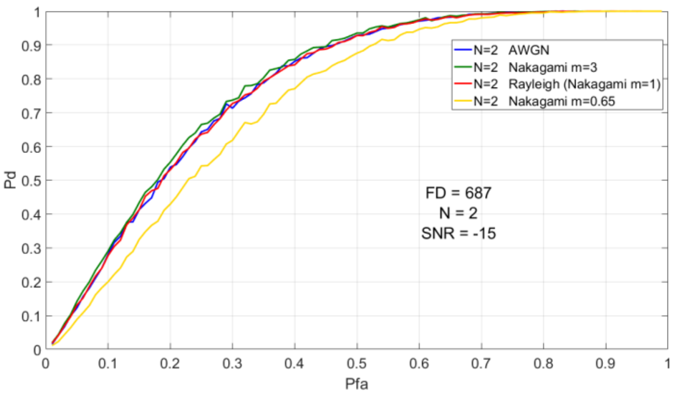

Fig. 7. The ROC curves for HD with maximum Doppler shift ($F_D = 687$).

The presented results show that multipath fading has a significant impact on HD efficiency only under specific conditions. Rayleigh's fading and mild *m*-Nakagami fading ($m = 3$) have no major impact on HD performance. Whereas severe fades significantly reduce both the probability of detection and the probability of false alarm for HD.

The maximum Doppler shift also does not affect the efficiency of HD. Significant differences can be observed only in the quasi-static case when the Doppler shift is small (it should be emphasized that the purpose of the simulations was to check influence of the Doppler shift on the possibility of detecting the PU signal, and not on the quality of its reception).

The low impact of Rayleigh fading and mild *m*-Nakagami fading on HD efficiency results from channel transmittance and the rate of fading (Fig. 2, Fig. 3). The fading has an influence on the received signal level. The longer the observation time, the lower the differences in the HD efficiency will be because the level of the received signal becomes averaged. Bigger differences occur in the case of fast detection (short observation time). If the signal level changes are fast enough (Fig. 2), their averaging makes the HD efficiency slightly lower. However, in the case of slow fading, short observation time can cause a significant reduction in HD efficiency.

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