Ray-Based Propagation Simulations for Probability of Missed Detection in Cognitive Radio Scenario

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I. Introduction

The ever expanding requirements of wireless resources to connect people and machines put more and more pressure on the radiofrequency spectrum. Considering its intrinsic limitation, the ”command and control” static frequency allocation scheme leads to a congestion of the spectrum itself. Cognitive radio is expected to be a solution to this problem by introducing an opportunistic use of the frequency bands that are not heavily occupied by licensed users [1]. One of the key points of this technique is the capability to reliably detect the actual use of spectrum by legitimate users, in order to avoid interference with cognitive ones [2].

In this work we present the generation of coverage maps in terms of probability of missed detection (PMD) for active user systems, e.g. GSM 900 and 1800 and UMTS. The analysis is carried out considering propagation dependent path-loss. This is evaluated using a deterministic ray-launching approach, that is able to provide accurate results in terms of scenario dependence at the cost of a significant computational complexity.

II. Energy detection and probability of missed detection

A basic energy detector is considered in order to indicate frequency occupancy within the bandwidth of consideration. Energy detecting is a non-coherent detection method, taking advantage of simplicity and not requiring a priori knowledge of primary user signal. The block-diagram of a typical energy detector is depicted in Fig. 1.

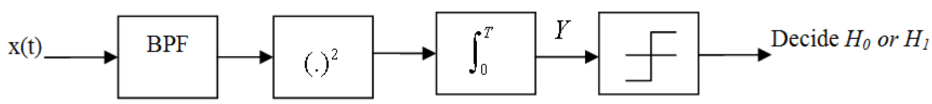

Fig. 1. Block diagram of a typical energy detector

The input signal first goes through a band-pass filter with a center frequency f_s, and bandwidth W. Then the received signal is squared and integrated during an observation time T. Finally, the output value Y is compared with a threshold λ to decide between two hypotheses. These two hypotheses are:

$$x(t) = \begin{cases} n(t) & H_0 \\ h \cdot s(t) + n(t) & H_1 \end{cases} \tag{1}$$

where $x(t)$ is the signal received by sensor, $n(t)$ is additive white Gaussian noise (AWGN), h is the channel impulse response in the time domain and $s(t)$ is the primary user transmitted signal. The hypothesis H_0 represents the absence of an active primary user within the sensor coverage zone in the targeted frequency band, while the hypothesis H_1 denotes the opposite case.

According to [3] the output of the integrator, Y, follows a chi-square distribution:

$$\overline{Y} = \begin{cases} \chi^2_{2TW} & H_0 \\ \chi^2_{2TW}\left(TW \cdot \gamma\right) & H_1 \end{cases} \tag{2}$$

where γ denotes the signal-to-noise ratio (SNR) and the AWGN has both the in-phase and quadrature modulation components. The chi-square distribution has $2TW$ degrees of freedom.

Normally, in a non-fading channel, we can compute the probability of missed detection P_{md} as

$$P_{md} = P\left\{Y < \lambda \mid H_1\right\} = 1 - Q_u\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \tag{3}$$

and the probability of false alarm (P_{fa}) as:

$$P_{fa} = P\{Y > \lambda \mid H_0\} = \frac{\Gamma(u, \lambda/2)}{\Gamma(u)} \tag{4}$$

where Q_u denotes the generalized Marcum Q-function, $\Gamma(\cdot)$ is the complete gamma function, $\Gamma(\cdot, \cdot)$ is the incomplete gamma function and $u = TW$.

Fig. 2 the receiver operating characteristics (ROC) curves of a sensor for different SNR levels and $TW = 10$. The curves express the available values of P_{fa} and P_{md} for different threshold values. As it can be expected, with increased SNR values, P_{fa} and P_{md} are decreasing and tending to zero. Nevertheless, for a given SNR, they are concurring as to have a lower P_{md} we must accept a higher P_{fa} and viceversa.

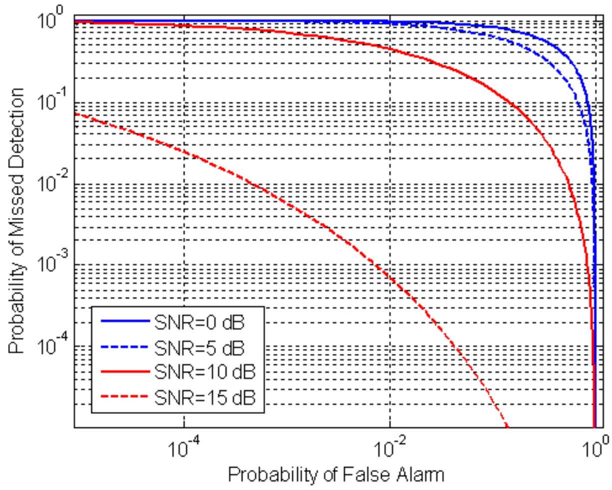

Fig. 2. ROC curves (PFA vs PMD) for different SNR levels and TW=10

In the following section, we present deterministic propagation simulations intended to calculate realistic SNR levels to estimate P_{md} in deterministic urban scenarios.

III. Generation of PMD maps with a ray-based deterministic tool

In recent years, ray-based deterministic tools have emerged as powerful options to elaborate site-specific propagation channel models. Radio waves emitted from the transmitter are treated as rays, in a high frequency approximation, and, exploiting Geometrical Optics (GO) principles are made interact with a deterministic environment. Interactions with surrounding objects taken into account are reflection, transmission, diffraction and, in some case, diffuse scattering. This deterministic approach can provide as result any propagation characteristics such as losses, delay and angular profiles.

The systems considered are GSM 900, GSM 1800 and UMTS with the carrier frequency of 900 MHz, 1800 MHz and 1950 MHz respectively. Realistic statistical distribution of transmitted power by user terminals of the three systems is also taken into account. Distributions are derived from [4]. The simulation scenario is a typical urban area in Paris around Place de la Republique. Four sensors are places on over-the-rooftop position, i.e. $3m$ above roof-top, while mobile terminals (MT) are uniformly distributed in the scenario at $1.5m$ above the ground level. The position of sensors is shown in Fig. 3.

We use a ray-launching tool to calculate the pathloss and, accordingly to deduce the P_{md} also considering the transmitted power distribution, taken into account as a random variable following a specific distribution. P_{md} maps are plotted to demonstrate the effective sensing coverage.

Fig. 4, Fig. 5 and Fig. 6 present coverage maps of P_{md} in non-collaborative sensor mode for GSM 900, GSM 1800 and UMTS, respectively. Due to high transmitted power in GSM systems, the coverage (in blue color) stretches along the main streets and some side-roads. Compared to GSM 1800, GSM 900 is operating at lower carrier frequency, which implies less path-loss by penetration and diffraction, leading to low PMD even within some buildings. Given that the transmitted power is much lower in the case of UMTS compared to GSM, the PMD coverage is quite poor, indicating the difficulty to detect such user.

What is allowing such a low MT transmitted power in UMTS system is an elevated processing gain. Unfortunately, this cannot be obtained by a non-coherent detector as the one used in this work. Therefore, to be effective for UMTS, the sensor should include the demodulation function of UMTS, which can increase the SNR up to 25 dB. That means the coverage may approach the one of GSM systems.

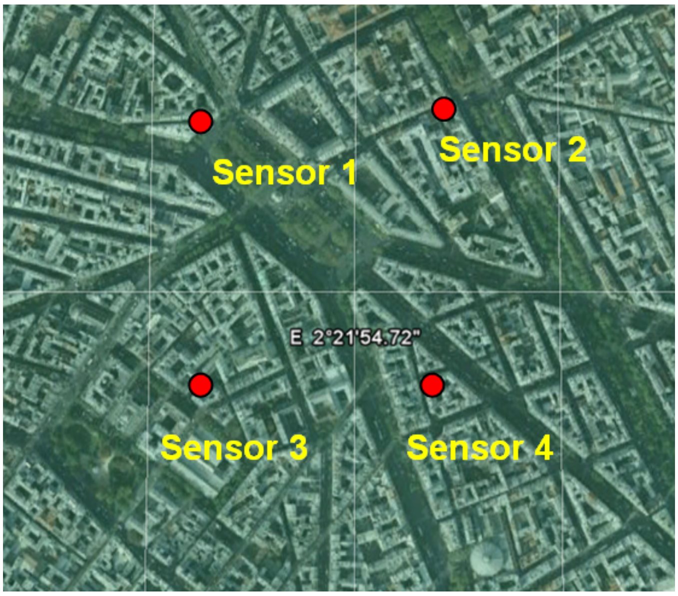

Fig. 3. Position of sensors in simulated area

IV. Conclusion

In this paper, we provided a formulation of P_{md} and P_{fa} for an energy detector employed to indicate frequency occupance in a cognitive sensor network scenario. Realistic distribution of transmitted power has been used to generate random variables of power emitted by the MT. A ray-based deterministic channel model has been used to simulate in a urban scenario the pathloss from MT to sensor. We, then, used these results to simulate the performance of sensors for three mobile communication standards: GSM900, GSM1800 and UMTS. The results showed the PMD coverage for GSM 900 and GSM 1800 is considerably large while for UMTS it is quite small. This happens because of the reduced MT transmitted power of this system. A pure energy detector is thus clearly insufficient for UMTS, and demodulating the signals has to be performed in order to improve the SNR by exploiting the processing gain of CDMA system. In the future, the processing gain of UMTS will be added to further research the improved performance of cognitive sensor network. The optimal distance between neighboring sensors will also be investigated.

Acknowledgment

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References

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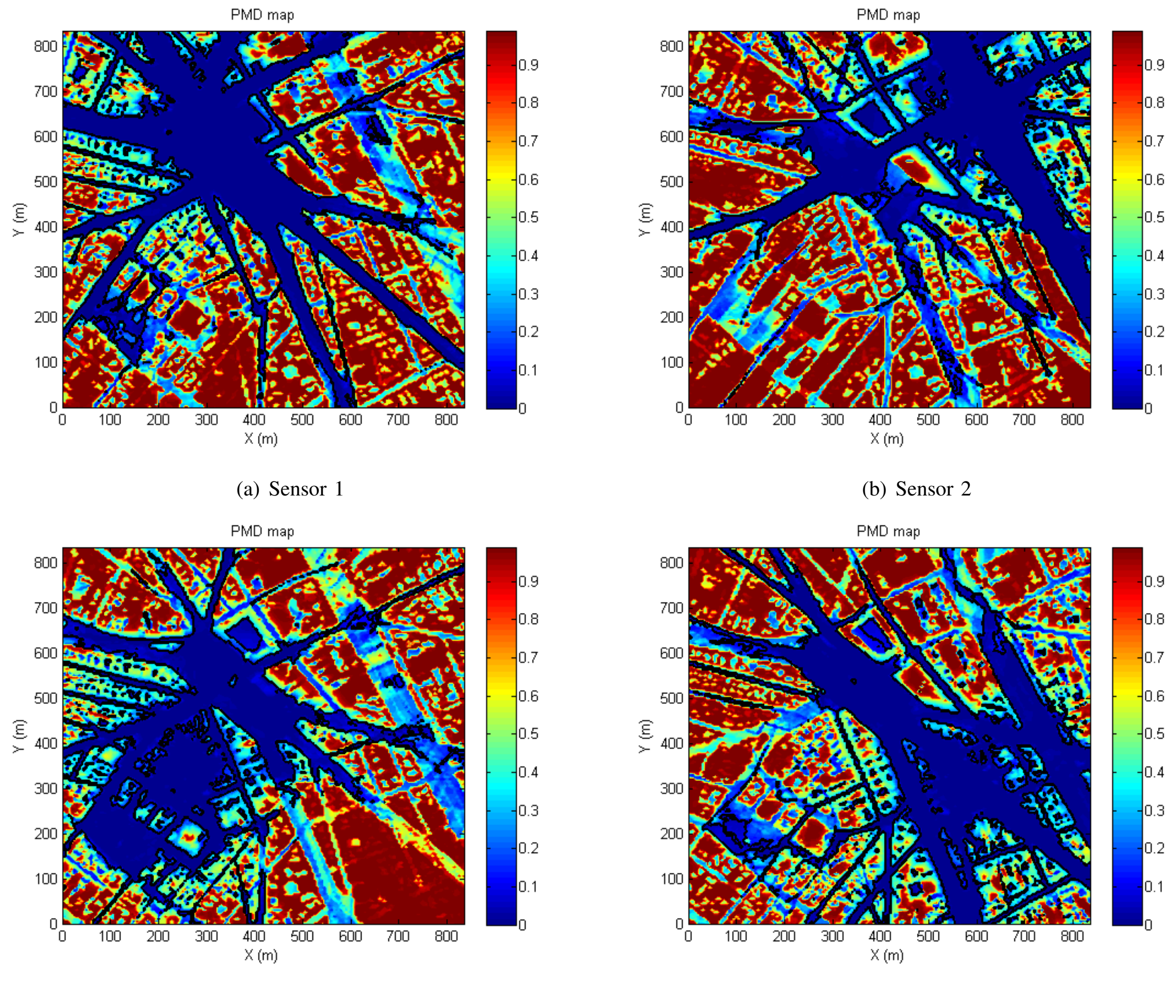


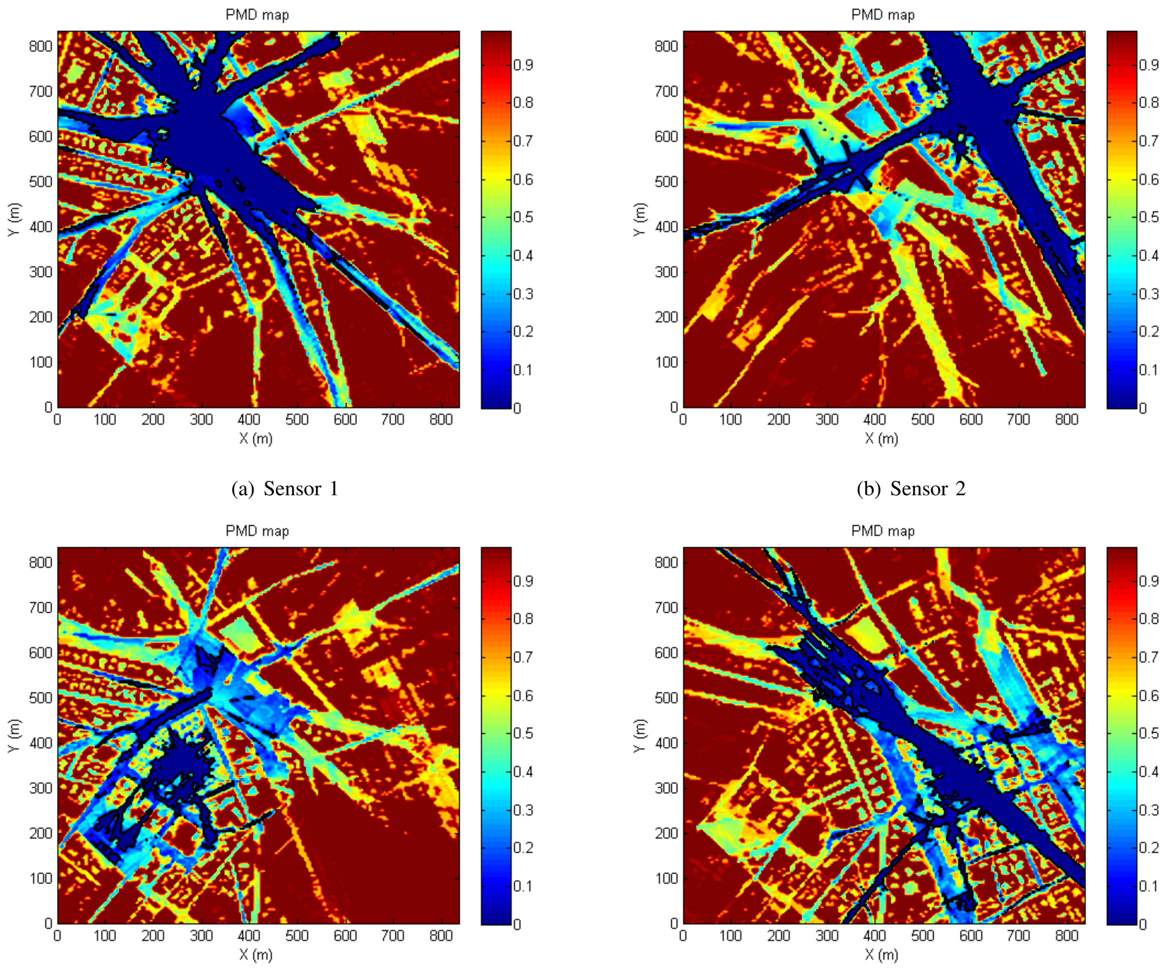
(a) Sensor 1

(b) Sensor 2

(c) Sensor 3

(d) Sensor 4

Fig. 4. PMD maps in case of GSM 900 for the different sensors



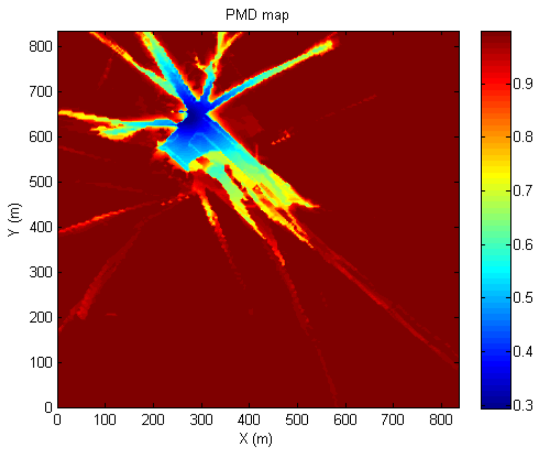
(a) Sensor 1

(b) Sensor 2

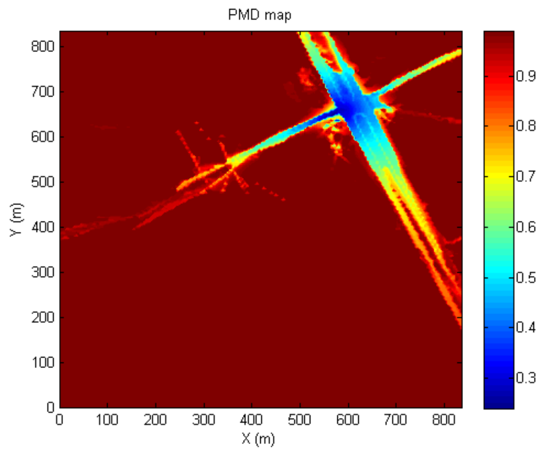
(c) Sensor 3

(d) Sensor 4

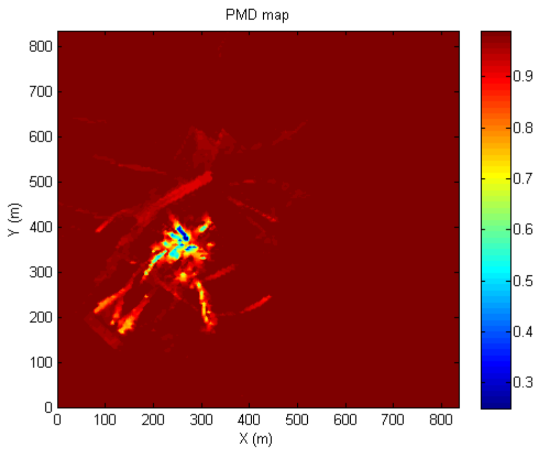
Fig. 5. PMD maps in case of GSM 1800 for the different sensors



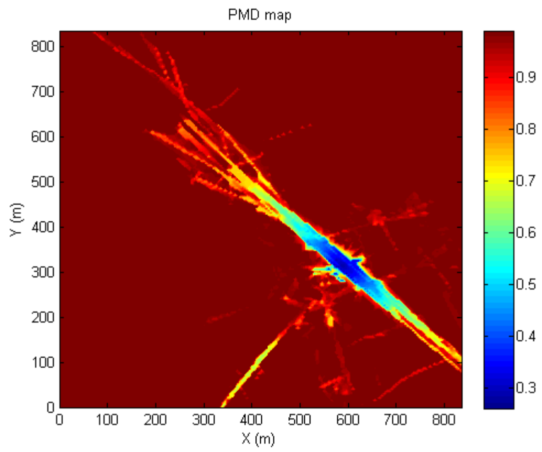
(a) Sensor 1



(b) Sensor 2



(c) Sensor 3



(d) Sensor 4

Fig. 6. PMD maps in case of UMTS for the different sensors