Use of Priors for Improving Blind Transmitter Detection in Cognitive Radios

Farrukh Javed+, Imran Shafee+, Asad Mahmood* and Heung-No Lee*

+CASE Islamabad, Pakistan. farrukh.javed@case.edu.pk, *Infonet Lab, Gwangju Institute of Science and Technology, Republic of Korea. asadmehmud@gist.ac.kr, heungno@gist.ac.kr

요 약 (Summary)

The classical transmitter detection based spectrum sensing techniques utilize Maximum Likelihood (ML) detection for classifying received signal as noise or actual transmission. The approach is prone to errors at low Signal to Noise Ratios (SNR) and variations in spectrum occupancy. This paper describes how prior information about spectrum occupancy can assist in improving power detectors' performance. The gain in performance achieved by replacing ML detector with a Maximum A-posteriori Probability (MAP) detector is calculated in terms of improvement in Sensing Error Floor (SEF). It has been shown that substantial gain in power detector's performance can be achieved in highly congested spectrum bands by use of MAP detectors.

Ⅰ. 서 론 (Introduction)

A cognitive radio (CR) [5] has the ability to identify any spectrum holes that exist in the spectrum band of interest and utilize them without causing any harmful interference to the licensed primary users [2]. A spectrum hole is the part of the spectrum that is devoid of the primary user transmission at a particular time and space. The process by which the CR identifies the existence of spectrum holes is termed as spectrum sensing and is a key challenge in CR implementation. Various spectrum sensing algorithms have been suggested [4] and most of these algorithms base their classification on binary hypotheses model using maximum likelihood (ML) detectors. The paper suggests a MAP detector based methodology that enables the CR to calculate a more accurate sensing threshold than the classical definition. This paper explores the effects of known channel occupancy (priors) on detector's performance. This scenario is most likely to arise in case of cooperative spectrum sensing where cooperating nodes can share spectrum occupancy data.

Ⅱ. 본론 (Main Part)

Assume that a signal $y(n)$ was received under AWGN $z(n)$, while the target signal was $x(n)$.

$$y(n) = x(n) + z(n) \tag{1}$$

The two possible hypothesis h_0 and h_1 for the received signal D in case of ML detection would be given as,

$$h_0 : D = \sum_{n=1}^{n_b} |z(n)|^2$$

$$h_1 : D = \sum_{n=1}^{n_b} |x(n) + z(n)|^2 \tag{2}$$

where n_b is the buffer size or observation time. The ML detector would be optimum if the priors are equal .i.e. $P(h_0) = P(h_1)$. ML hypothesis is given by,

$$h_{ML} = argmax_{h_i \in H}\ p(D|h_i)$$

The ML detection has been extensively used in various spectrum sensing algorithms and has been thoroughly investigated. In accordance with central limiting theorem $p(D|h_i)$ can be assumed as Gaussian with mean and standard deviation μ_i and σ_i respectively. The minimum possible detection error [3] of the sensing algorithm is termed as sensing error floor (SEF). The SEF_{ML} has been deduced for ML detection in [1]. If $Q(.)$ indicates the Q – function,

$$SEF_{ML} = Q\left(\frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0}\right) = Q\left(\sqrt{\frac{n_b}{2}}\frac{SNR}{1+\sqrt{\left[\frac{\alpha-1}{2}\right]SNR^2+2SNR+1}}\right) \quad (3)$$

Where α is a measure of randomness of the signal $x(n)$ and $\alpha = E[|x(n)|^4]/\{E[|x(n)|^2]\}^2$. In case the priors are not same (which would invariably be the case) the MAP hypotheses for the same model would be given by

$$h_{MAP} = argmax_{h \in H}\ p(h|D) \quad (4)$$

As the result is independent of $p(D)$ the hypothesis is reduced to

$$h_{MAP} = argmax_{h \in H}\ p(D|h)P(h) \quad (5)$$

The mean and standard deviation of the MAP distribution would be changed according to priors. The sensing threshold (ST) used to differentiate the signal from noise is now changed to,

$$ST = {\sigma_z}^2\left[n_b\left(1 - \frac{SNR}{2SNR+\left[\frac{\alpha-1}{2}\right]SNR^2}\right) + \sqrt{2n_b \ln(\beta^{-2})}\right] \quad (6)$$

where β is the ratio of priors $\beta = \frac{P(h_1)}{P(h_0)}$. The SEF will also change to,

$$SEF_{MAP} = Q\left(\sqrt{\frac{n_b}{2}}\frac{-SNR}{2SNR+\left[\frac{\alpha-1}{2}\right]SNR^2} + \sqrt{ln(\beta^{-2})}\right) \quad (7)$$

Sensing error floor has been considered as a comparison metric for the two approaches. The condition under which priors will bring an improvement in detection process is based on monotonically decreasing property of Q-function. Thus for any $f_1 = Q(n_1)$ and $f_2 = Q(n_2)$ the condition $n_2 \geq n_1$ must hold true if $f_1 \geq f_2$. Therefore in order for SEF_{ML} to be greater than SEF_{MAP} following condition must hold true,

$$\sqrt{\frac{n_b}{2}}\frac{-SNR}{2SNR+\left[\frac{\alpha-1}{2}\right]SNR^2} + \sqrt{ln(\beta^{-2})} \geq \sqrt{\frac{n_b}{2}}\frac{SNR}{1+\sqrt{\left[\frac{\alpha-1}{2}\right]SNR^2+2SNR+1}}$$

This condition can be approximated as:

$$ln\frac{P(h_0)}{P(h_1)} > \frac{n_b}{4}SNR^2 \quad (9)$$

Thus the MAP detection would outperform ML detection if equation [9] is satisfied. The amount of gain in performance $G = \frac{SEF_{MAP}}{SEF_{ML}}$ can be simplified using Chernoff bound for Q – function as,

$$G = exp\left[\frac{n_b}{4}SNR^2\left\{1 + ln\left(\beta^{\frac{4}{n_b SNR^2}}\right)\right\}\right] \quad (10)$$

Ⅲ. 결론 (Conclusion)

Classical transmitter detection techniques use ML detection for spectrum sensing. This approach is not optimal if the prior probabilities of spectrum hole and spectrum occupancy are not same. This paper suggests use of priors for optimizing the classification of signal and noise in a cognitive radio. The conditions under which the MAP detector will outperform ML detector have been deduced. It has been shown that the use of MAP detection enhances detector's efficiency only under specific spectrum conditions. The future of cognitive radios is in the more congested bands and this information can be very critical. The gain that can be expected using MAP detection has been analytically deduced.

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참 고 문 헌 (References)

[1] Haiyun Tang. Some Physical layer issues of wide-band cognitive radio systems. DySPAN 2005, pp. 151-159.
[2] FCC, ET Docket No 03-222. Notice of proposed rule-making and order. December 2003.
[3] SENDORA. SEnsor Network for Dynamic and cOgnitive Radio Access, website. http://www.sendora.eu/.
[4] Y¨ucek and Arsalan, “A survey of spectrum sensing algorithms for cognitive radio applications,” IEEE Communication Surveys & Tutorials, vol. 11, no. 1, pp. 117-122, first quarter, 2009.
[5] Linda Doyle, “Essentials of cognitive radios,” Cambridge wireless essentials series, Cambridge university press, 2009, pp. 96–105.