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Optimal Spectrum Sensing Approach on Cognitive Radio Systems

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Abstract: In order for the unlicensed or secondary users to use the licensed spectrum cognitive radio has been proposed. The licensed frequencies can be made use of by unlicensed users through dynamic spectrum access so as to reduce spectrum scarcity. This requires intelligent spectrum sensing techniques. The detection of unused frequency bands is the most challenging task in cognitive radio. In this study such unused spectrum is predicted by exploring the primary users presence in minimum time using matched filter based detection incorporating optimal threshold selection, thereby increasing the sensing accuracy and interference reduction of secondary network.

Keywords: Likelihood ratio test, matched filter, spectrum efficiency

INTRODUCTION

The need for a flexible and robust wireless communication is becoming more evident in recent times. The future of wireless networks is thought of as a union of mobile communication systems and internet technologies to offer a wide variety of services to the users.

Conventionally, the policy of spectrum licensing and its utilization lead to static and inefficient usage (Haykin, 2005). The requirement of different technologies and market demand leads to spectrum scarcity and unbalanced utilization of frequencies. It has become essential to introduce new licensing policies and co-ordination infrastructure to enable dynamic and open way of utilizing the available spectrum efficiently. Cognitive radio is a best solution to increase the spectrum efficiency through spectrum sensing techniques (Haykin, 2005). It is necessary to have maximum accuracy in predicting the presence of primary user to reduce interference. An optimal way of detecting the spectrum holes has been discussed in rest of this study.

LITERATURE REVIEW

Spectrum sensing methods: The most important factor of cognitive radio is spectrum sensing (Haykin, 2005). In fact it is the foremost step that needs to be performed for communication to take place. A number of schemes have been developed for detecting whether the primary user is present in a particular frequency band. Some approaches use the signal energy or some particular characteristics of the signal to identify the signal and even its type.

Some of the most common methods employed for Spectrum Sensing (Yucek and Arslan, 2009) are:

- Energy Detector (Shipra and Ghanshyam, 2011)
- Cyclo-stationary detector (Maleki *et al*., 2010)
- Matched Filter Technique (Liangping *et al*., 2012)

Among the above three methods energy detection is popular till now, but the major drawback with energy detection method is that the poor performance under low SNR conditions and also no proper distinction between primary users and noise. Rather the matched filter maximizes the SNR (Ghasemi and Sousa, 2008).

Brief introduction to matched filter: The decision making on whether the signal is present or not can be facilitated if we pass the signal through a filter, which will accentuate the useful signal sig (t) and suppress the noise w (t) at the same time. Such a filter which will peak out the signal component at some instant and suppress the noise amplitude at the same time has to be designed. This will give a sharp contrast between the signal and the noise and if the signal sig (t) is present, the output will appear to have a large peak at this instant. If the signal is absent at this instant, no such peak will appear. This arrangement will make it possible to decide whether the signal is present or absent with minimum probability of error. The filter which accomplishes this is known as matched filter. Main purpose of the filter is, to decrease the noise component and to increase the signal component at the same instant. This is obviously equivalent to maximizing the ratio of the signal amplitude to the noise amplitude at some instant at the output. It proves more convenient if we go for square of amplitudes. Hence the matched filter is designed in such a way that it will maximize the ratio of the square of signal amplitude to the square of the noise amplitude.

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METHODOLOGY

Non-co-operative matched filter detection: Let sig (t) be the transmitted signal, w (t) is the channel noise, sig (t) + w (t) is given as the input to the matched filter and sig_0 (t) + w_0 (t) be the output of the filter, where sig_0 (t) is the signal component at the output and w_0 (t) is the noise component at the output. Let the matched filter's impulse response be h (t). It had been proven that, impulse response of the optimum system is the mirror image of the desired message signal sig (t) about the vertical axis and shifted to the right until all of the signal sig (t) has entered the receiver. It should be realized that the matched filter is optimum of all linear filters.

The signal component at output of the filter, at the observing instant t_m is given by:

$$sig_0\,(t_m) = 1/2\pi\int (s\,(\omega))^2 \tag{1}$$

$$sig_0\,(t_m) = E \tag{2}$$

Hence the maximum amplitude of the signal component at the output has magnitude E, the energy of the signal sig (t). The maximum amplitude is independent of the waveform sig (t) and depends only upon its energy.

Figure 1 shows Spectrum Sensing block using matched filter. Here the transmitted signal is passed through the channel where the additive white Gaussian noise is getting added to the signal and outputted the mixed signal. This mixed signal is given as input to the matched filter. The matched filter input is convolved with the impulse response of the matched filter and the matched filter output is then compared with the threshold for primary user detection.

Threshold in matched filter detection: Let t_m = T be the time instant at which the matched filter is expected to produce a maximum signal to noise ratio. The detection of presence of signal sig (t) is therefore decided at the matched filter output at the observation instance t = T. If the matched filter output is taken as rxd (t), then:

$$rxd\,(T) = sig_0\,(T) + w_0\,(T) \tag{3}$$

From Eq. (2):

$$rxd\,(T) = E + w_0\,(T) \tag{4}$$

Since the noise input is random, w_0 (T) is also random. The output rxd (T) is given by a constant E plus the random variable w_0 (T) indicates the presence of signal at the input. Therefore the output will differ from E by noise amplitude. If there is no signal sig (t) at the input, the output of the filter will be given by noise term:

$$rxd\,(T) = w_0\,(T) \tag{5}$$

The exact value of w_0 (T) is unpredictable because of the randomness of the signal. It can be a positive or negative value and also may be a large or a small value. Hence there is a possibility for the signal to be present at the input and predicted to be absent at the output because of the large negative value of w_0 (T). Similarly, there is a possibility for the signal to be absent at the input and predicted to be present at the output because of the large positive value of w_0 (T). Thus there is no sure way of deciding the presence and absence of signal sig (t) and there is always some likelihood of error. This likelihood of error can be minimized by proper decision rule (Cabric *et al*., 2004).
Decision rule:

$$rxd\,(t) > a\text{: Signal present} \tag{6}$$

$$rxd\,(t) < a\text{: Signal absent} \tag{7}$$

For a given threshold 'a', two types of errors can be observed. Error of False alarm is the probability that rxd> 'a' during the absence of the signal. False dismissal is the probability that rxd< 'a' when the signal is actually present. If the signal sig (t) is equally likely to be present and absent, then on the average, half the time sig (t) will be absent and the remaining half time sig (t) will be present. The probability of error in the decision will be given by the sum of above two errors. Hence for minimum probability of error, the optimum threshold is given by a = E/2 and the corresponding error probability is given by:

$$P_e = \text{erfc (sqrt (E/2 * power density spectrum of noise))} \tag{8}$$

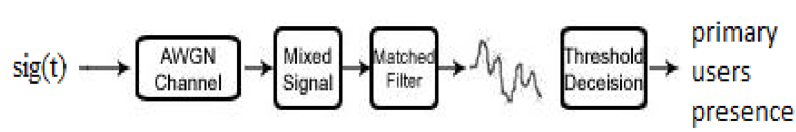

Fig. 1: Block diagram of spectrum sensing using matched filter

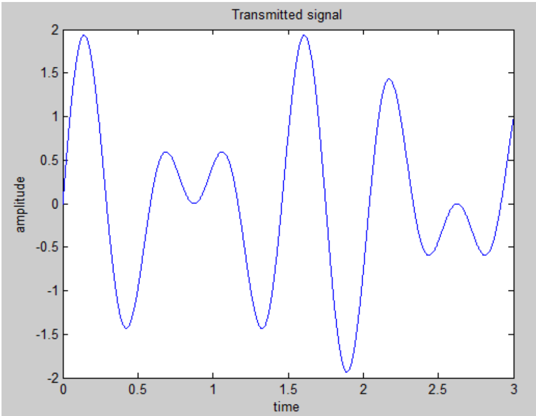

Fig. 2: Transmitted signal

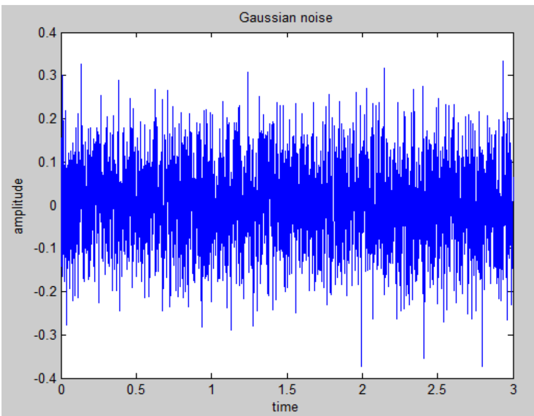

Fig. 3: Additive white Gaussian noise

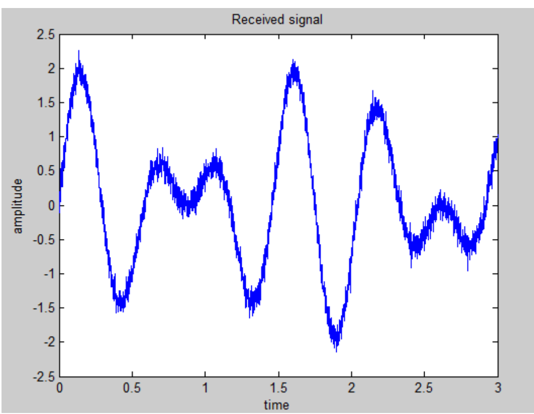

Fig. 4: Input to the matched filter

RESULTS AND DISCUSSION

Figure 2 shows the transmission of signal by the primary user sig (t). The randomly generated additive white Gaussian noise is represented in Fig. 3. The transmitted signal which when passes through the channel gets affected by the additive white Gaussian noise is shown in Fig. 4. This signal is given as input to the matched filter and is convolved with the impulse response of the filter. The Fig. 5 depicts the corresponding output of the Matched Filter. This Matched Filter output reveals that wherever the presence of primary user is observed there occurs a peak. In other words the absence of primary users location corresponds to the spectrum holes as per the implementation issues in spectrum sensing.

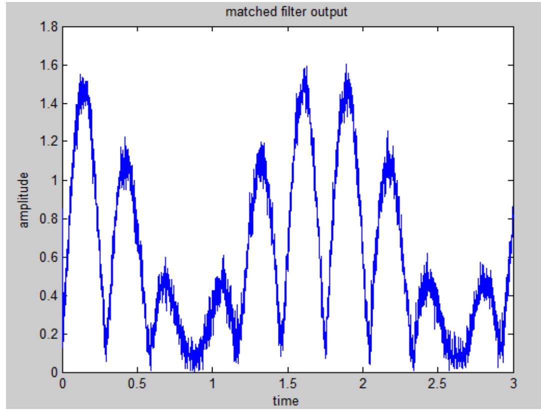

Fig. 5: Matched filter output

Table 1: Detection of primary user

Sample range	Number of detections
1-500	322
501-1000	0
1001-1500	136
1501-2000	368
2001-2500	134
2501-3000	2

The Matched filter is observed for every 500 samples and the corresponding number of primary users presence for every 500 samples tabulated in Table 1. On comparing the number of detections listed in Table 1 and the output of matched filter represented in Fig. 5, it is clear that the presence of primary user is more in the time period 0-0.5 and 1.5-2, medium in 1-1.5 and 2-2.5, very less in 2.5-3 and no user is present in 0.5-1. Thus the frequencies corresponding to sample range given in Table 1 specifies the spectrum holes.

CONCLUSION

To account for spectrum scarcity problem and spectrum underutilization the cognitive radio inclusive of spectrum sensing unit has been incorporated. One of the most important factors of spectrum sensing for CR network is sensing accuracy. The presented study focuses on improve the sensing accuracy by optimal prediction of primary users presence in minimal time with the help of optimal threshold fixing in matched filter. This reveals that the interference produced by secondary network to primary network gets minimized. The major limitation here is, it requires prior knowledge of the primary user signal. This study can be made more efficacious by including interference management technique.

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