Cooperative Spectrum Sensing by Sequential Change Detection in Cognitive Radio

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ABSTRACT

This paper proposes the solution for Spectrum Sensing Problems in Cognitive Radio Networks. For this an Adaptive CUSUM based Test for signal Change Detection algorithm is used. The algorithm is based on sequential change detection techniques which is particularly effective when the parameters are not available a-priori or when the correct parameter configuration and the pdf of the signal under test are unknown. This work provides an extension of the CUSUM algorithm which allows the test parameters to be configured. The proposed Adaptive CUSUM provides accuracy, change detection readiness and computational complexity.

Keywords: Cognitive Radio, change detection, spectrum sensing, Adaptive CUSUM.

I. INTRODUCTION

Cognitive Radio uses the radio spectrum of the other users. They perform radio environment analysis, identify the spectral holes and then operate in those holes. In cognitive radio terminology Primary user refers to a user who is allocated the rights to use the spectrum. Secondary user refers to the users who try to use the spectrum bands allocated to the primary user when the primary user is not using it [1].

Spectrum sensing is an essential component of the Cognitive Radio technology which involves, identifying spectrum holes, and when an identified spectrum hole is being used by the secondary users, to quickly detect the onset of primary transmission. This needs to be done such that the guaranteed interference levels to the primary are maintained and there is efficient use of spectrum by the secondary. This involves detecting reliably, quickly and robustly, possibly weak, primary user signals [1-2]. Hence, Cooperative Spectrum Sensing is required, whereby the spatial diversity inherent in radio environment is leveraged by allowing multiple secondary users to cooperate. This reduces the average time to detect the primary user. This in turn lowers the interference to the primary user, while increasing the spectrum usage of the secondary user [2]. Depending on the amount of information about a primary user's parameters available at a cognitive user, various detection schemes have been developed for this application. In addition to the detection probability, the detection delay is also an important performance metric in cognitive radio detection. If a primary user stops transmission, then a secondary user should detect this event quickly, in order to be able to start own transmission quickly. A small detection delay will allow the design of a spectrum reuse scheme that has minimal impact on the licensed users [5].

II. MODEL AND ALGORITHM

A) Model
Consider a Cognitive Radio System with L secondary users who sense a channel via Energy Detectors. The observations made on the channel by these users are processed and sent to a fusion center which makes a decision whether the channel is free or not. Then that decision is sent to all secondary users for possible use
of channel. The secondary nodes have to detect the change in the status of the channel in two situations. First, when the primary has been using the channel and it stops transmission. The secondary nodes have to cooperatively detect this change as soon as possible so that they can make maximum use of the available channel. The second situation is when the channel has been free and the secondaries are using the channel. They need to sense the channel to see if the primary starts transmission. It is difficult to detect this when the secondaries are transmitting, especially when the energy detection method is used. Thus, in between their transmissions, secondary’s stop intermittently for a few slots and sense the channel to see if primary has started transmission. If yes the secondary’s need to stop using that channel. To minimize interference to the primary, this also needs to be done quickly [1], [2].

The aim is to detect the change at the fusion center as soon as possible at a time $\tau$ using the messages transmitted from the L sensors with an upper bound on probability of false alarm. For this each of the L nodes uses its observation $X_{k,l}$ to generate a signal $Y_{k,l}$ and transmits to the Fusion Center. The data received at the fusion center is corrupted by the i.i.d. receiver noise $Z_k$ at the fusion node. The fusion center uses the observations $Y_{k,1}, Y_{k,2}, \ldots, Y_{k,L}$ to decide between the two hypotheses $H_0$ and $H_1$. If $H_0$ is chosen the secondaries continue to use the channel in slot $k$ and the spectrum sensing session continues. If $H_1$ is detected, the secondaries typically switch over to an alternate channel. To transmit $Y_{k,1}, Y_{k,2}, \ldots, Y_{k,L}$ from the L secondaries to their fusion node, they need a Multiple Access Channel (MAC) protocol. Time Division Multiple Access (TDMA) is the most commonly used protocol. We will allow all nodes to transmit simultaneously and use physical layer fusion. This saves time in transmission [1].

III. COOPERATIVE SENSING ALGORITHMS

As explained in [1-2], DualCUSUM and CUSUM (developed in [3]) algorithms run at the local (secondary) nodes. If it crosses a threshold $\gamma$ then it transmits a message to the fusion node. There is physical layer fusion at the fusion node of all the transmissions from different secondaries. The fusion node also runs CUSUM based on its input and finally declare a change if it’s CUSUM process exceeds a threshold $\beta$.

A) DualCUSUM Algorithm

1) Each of the secondary users $l$ runs Parametric CUSUM algorithm [1].
$$z_{k,l} = \max \{ 0, W_{k-1,l} + \xi_{k,l} \}, W_{0,l} = 0$$
where,
$$\xi_{k,l} = \log \frac{f_{1,l}(X_{k,l})}{f_0(X_{k,l})},$$
$f_{1,l}$ is the density of $X_{k,l}$ under $H_1$ and $f_0$ is the density of $X_{k,l}$ under $H_0$.

2) Secondary user $l$ transmit at time $k$, only if $W_{k,l}$
$$Y_{k,l} = b1_{\{W_{k,l} > \gamma\}}.$$ The parameters $b$ and $\gamma$ are chosen appropriately. This censoring allows saving energy, and causing less interference to others.

3) At the fusion center we assume physical layer fusion: $z = \sum_i Y_{k,i} + Z_k$ where $Z_i$ is i.i.d. noise at the fusion node.

4) Change detection at the fusion center via CUSUM:
$$c = \max \{ 0, F_{k-1} + \log \frac{g_F(z_k)}{g_0(z_k)} \}$$ where $g_F$ is the density of $Z_i$ and $g_0$ is the density of $Z_i + bl, l$ being a design parameter.

5) The Fusion Center declares a change at time $[\beta, \gamma, b, I]$ when $F_i$ crosses a threshold $\beta$.
$$[\beta, \gamma, b, I] = \inf \{ k; F_k > \beta \}.$$ Though DualCUSUM is probably not optimal, it has some desirable features:
(i) it uses past observations at the local nodes as well at the fusion nodes;
(ii) local nodes employ censoring before transmitting
(iii) physical layer fusion is exploited in transmitting the data to fusion node [1-2].

B) Adaptive CUSUM Algorithm

Dual CUSUM assumes that both $f_{1,l}$ and $f_0$ are available. In Cognitive Radio the difficulty is in obtaining perfect knowledge of $P_i$, the primary’s power and the noise power $\sigma_i$ [1], [2].

DualCUSUM algorithm used at the secondary nodes is replaced by the Adaptive CUSUM algorithm.

Let the density of $X_{k,l}$ be $f_0$ before change and $f_0$ after change, where $\theta$ is a parameter that characterizes density after change.

To measure the discrepancy between the two pdfs at time $t$ consider the log-likelihood ratio
\[ s_t = \ln \frac{f_\theta(X_{k,t})}{f_0(X_{k,t})} \text{ for each } 1 \leq t \leq N \]

And evaluate the cumulative sum
\[ z_t = \sum_{i=1}^{t} s_t \] CUSUM identifies a change in \( X_k \) at time \( t \) when the difference \( g_t \) between the value of the cumulative sum \( S_t \) and its current minimum value \( m_t \) at time \( t \) is larger than a given threshold value \( \beta \)
\[ g_t = S_t - m_t \geq \beta, \quad m_t = \min_{1 \leq i \leq t} S_i \]

Very rarely parameters \( f_0, f_\theta, \) and \( h \) are available at design-time. When this does not happen the designer has to provide an estimate based on a trial and error basis. In the following, we suggest a configuration procedure which allows the designer for automatically and adaptively identify the needed parameters. The procedure can be as follows:

1) Define the configuration sequence
2) Estimate the \( f_\theta \) parameter
3) Evaluate the \( f_0 \) parameter
4) Evaluate the \( h \) parameter

Consider the first \( K \) instances of \( X \) (with \( K<N \)) as configuration sequence
\[ TS = \{x_i: 1 \leq i \leq K\} \]

To compute the log-likelihood ratio the knowledge of probability density function of the stochastic process is required. If it is not available, as it is mostly the case, we generate a cumulative sequence \( Y=\{y_1, y_2, \ldots\} \) from \( X \).

V. CONCLUDING REMARKS
In this paper an extension of CUSUM, Dual CUSUM is presented to change detection test to overcome the need to configure at design time the parameters. Automatic configuration of parameters is also proposed. A change detection approach was setup and the use of the adaptive approach is very appealing both when correct parameters are not available a-priori and when the pdf of the signal is not known. This approach is very useful in spectrum sensing of Cognitive Radio environments where the signal information is readily not available at the fusion center (suitable for cognitive radio systems).

REFERENCES