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Cognitive Radio Using Multicoset Sampling for Wideband Spectrum Sensing

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ABSTRACT: *The entire operation of Cognitive Radio rests based on Spectrum sensing. Spectrum sensing is a system which figures out if a given frequency band is utilized. In this paper, to propose a spectrum sensing technique based on the estimate of the spectrum of a multiband signal obtained from its non-uniform compressed multicoset samples. This proposed spectrum sensing method gives accurate results by using less data samples. The effect of false detections on the quality of the reconstructed signal obtained from non-uniform multicoset sample*

INDEX TERMS: *Non-uniform sub-Nyquist sampling, Multicoset sampling, Cognitive radio, Spectrum sensing*

I. INTRODUCTION

The available electromagnetic radio spectrum is a valuable however confined natural aid. Cognitive Radio (CR)is a new technology at wireless communications, has the potential to become the solution to the spectrum under utilization problem, by allowing unlicensed users to access these spectrum holes for transmission [1]. The main cognitive task is to develop wireless spectral detection and estimation techniques for sensing the available spectrum. Spectrum sensing can be defined as the task of detecting the presence or absence of a signal by sensing the radio spectrum. Some known popular spectrum sensing techniques are energy detection, matched filter detection and cyclostationary feature detection that have been proposed for narrow band sensing [2]. All these techniques function by filtering the received signal with narrowband band-pass filters and then sample it uniformly at the Nyquist rate. In these approaches to spectrum sensing, the detection method boils right down to a binary speculation-trying out trouble i.e. to detect presence (H1) or absence (H0) of a primary user in the considered band.

It is well known that with the advances in wireless communications, future cognitive radios should be capable of scanning a wideband of frequencies, in the order of few GHz. The usual sampling of a wideband signal needs high sampling rate ADCs, which need to operate at or above the Nyquist rate. The above mentioned spectrum sensing techniques have their respective advantages and disadvantages over one another. But a common drawback is that techniques operate at Nyquist sampling rate. Since, sampling a wideband at Nyquist rate followed by the processing of large amount of sampled data in real time requires a lot of effort and poses a major implementation challenge in term of processing speed and power consumption.

To overcome this problem, solutions based on compressive sampling have been proposed in [3][5]. In [3], the signal is detected from the estimated spectrum obtained from the compressed samples of the signal. However, spectrum estimation of a signal from its compressed samples is achieved by solving an optimization problem, which is not an easy task. Using the fact that the wireless signals in open-spectrum networks are typically sparse in the frequency domain, in [5], a sensing method based on MUSIC algorithm has been proposed. Authors in [5] claim that the proposed method would bring substantial saving in terms of the sampling rate. However, the performance of the proposed method degrades at low SNRs and also requires more data samples to correctly detect the signal.

In this paper, based on the multiband signals in frequency domain and using non-uniform sub-Nyquist Multicoset sampling of the input signal, we propose a wideband spectrum sensing method for the detection of

active bands that would bring substantial saving in terms of the sampling rate. The performance of the proposed method is examined at low SNR values with less data samples and is found to produce accurate results. The impact of the false-detections of the proposed sensing method on the reconstructed signal is also analyzed. The remainder of the paper is organized as follows. In Section II the signal model and problem statement. In Section III, an overview of multicoset sampler is given and the proposed non-uniform spectrum sensing method is presented in Section IV.

II. SIGNAL MODEL AND PROBLEM STATEMENT

To recover Nyquist rate samples of the received signal from sub-Nyquist Multicoset samples, the knowledge of the number of bands NB and K is of paramount importance [6]. These parameters are indispensable to reconstruct the time domain signal but are unknown to the system. Therefore, based on this discussion our problem is: Given the observation band,

B=[fmax] the objective is to correctly detect the active cells set K for optimal reconstruction of the non-uniformly sub-Nyquist sampled signal x(t) and to analyze the impact of false detections of K on the averaging sampling rate of the system.

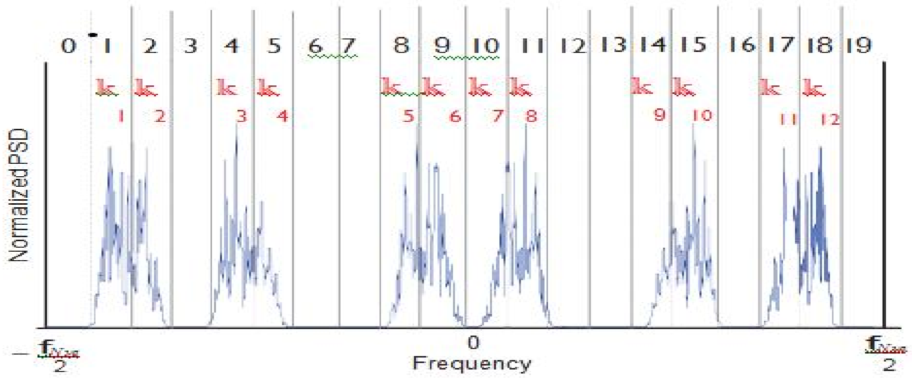

Figure 1: Division of the observation band into L = 20 cells where K ={kr}12 r=1 are the indexes of the active cell.

III. MULTICOSET SAMPLER

A complete block diagram of a Multicoset sampler along with the proposed non-uniform spectrum sensing scheme is shown in Figure 2. The received analog signal is sampled by the multicoset sampler at a rate lower than the Nyquist sampling rate. The multicoset samples are then sent to the non-uniform spectrum sensing block. The non-uniform sensing block performs spectrum detection and computes the parameters NB and K required for signal reconstruction in the reconstruction block.

In this paper, our objective is to study the performance of the proposed non-uniform sensing method. Therefore, we give an overview of the multicoset sampling scheme. Multicoset sampling is a periodic non-uniform sampling technique which samples the input signal x(t) at a rate lower than the Nyquist rate, thereby capturing only the amount of information required for an accurate reconstruction of the signal. Multicoset sampling starts by choosing an appropriate sampling period T, less than or equal to the Nyquist period associated to x(t). Then the input signal x(t) is non-uniformly sampled at ti(n) = (nL + ci)T, where $1 \le i \le p$ and n Z [9]. The set C = {ci} contains p distinct integers from {0, 1, ,L − 1} and is termed as the sampling pattern. The parameters L and p are selected such that $L \ge p > 0$. The process of multicoset sampling can be viewed as first sampling the input signal at a uniform rate with period T and then selecting only p non-uniform samples from L equidistant, uniform samples (see Figure 3). The process is repeated for consecutive segments having L uniform samples each such that the p selected samples have a sampling period L. The set C specifies the p samples that are retained in each segment of length L such that $0 \le c1 < c2 < ... < cp \le L - 1$. Multicoset

sampler is usually implemented by placing p ADCs in parallel [10]. Each ADC operates uniformly at a period Ts = LT . The multicoset sampler, therefore, provides p data sequences for i = 1- p

$$xi = x(nL + ci)T = (n + \frac{c}{L})T_s \qquad (1)$$

where 1 ≤ i ≤ p. The average sampling rate of this scheme is $f_{avg} = \_f_{Nyq}$. In order to perform recover the signal x(t) sampled at sub Nyquist rate, NB and K must be known to the reconstruction block [6].

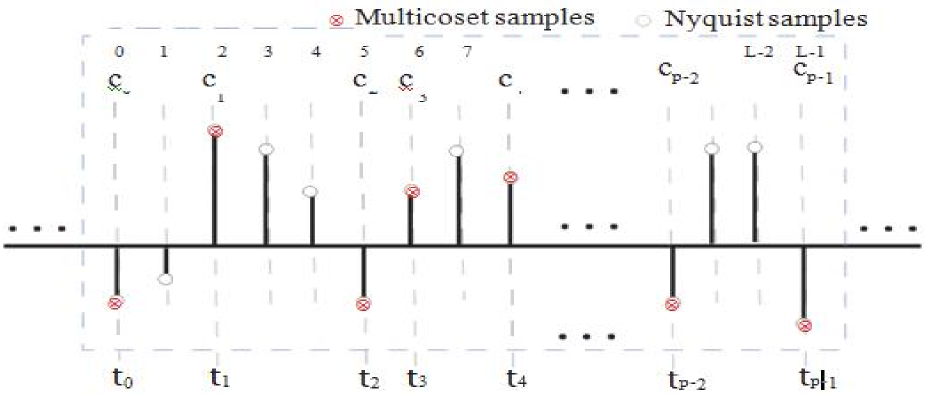

Figure 2: L uniformly spaced Nyquist samples and corresponding p multicoset samples.

IV. BASIC STRUCTURE OF REGULAR 16-BIT CSLA

In this section we discuss our proposed Non-Uniform Spectrum Sensing Block (NUSS) (shown in dotted block in Figure 2 to compute the parameters NB and K to allow successful reconstruction of x(t). The function of each sub block is explained in the subsections to follow

A. NON-UNIFORM SPECTRUM ESTIMATION BLOCK

As stated in Section II, our objective is to detect the total number of bands NB and the set of active cells K. Since, the input signal x(t) is under sampled and the samples are not evenly spaced, the usual spectrum sensing techniques like FFT based energy detection and cyclostationarity cannot be used [2]. In order to overcome this hurdle, we treat this scenario as a missing data problem and in this paper we propose to use the Lomb-Scargle method [11] to estimate

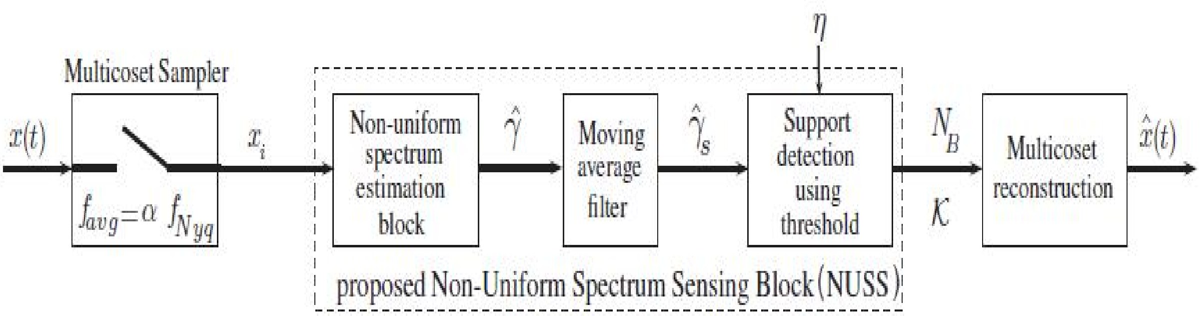

Figure.3: Multicoset Sampler for wideband signals along with the proposed Non-uniform spectrum sensing method shown within the dotted block.

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The power spectral density (PSD) of the non-uniformly sampled signal. Then in the remaining sub blocks of the sensing model, N_B and K are computed from this estimated PSD. The Lomb-Scargle periodogram is a well known tool to detect if an unevenly spaced data is due to noise or it contains also the contribution of a signal by providing an estimate of the PSD.

Lomb-Scargle method evaluates the samples, only at times tn that are actually measured. Suppose that there are Ns samples x(tn), n = 1, ...,Ns. The PSD estimate obtained from Lomb-Scargle method is defined by (2) (spectral power as a function of angular frequency $f_{Nyq}= 2f_{max} > 0$ with f ∈B = $[-\frac{f}{2}, \frac{f}{2}]$.

B. MOVING AVERAGE FILTER BLOCK

It is observed that the PSD estimate ˆ obtained from the Lomb-Scargle method has a high variance. As a result of which N_B and K are not easy to detect if the PSD estimates are used in their original form. Therefore, we use a moving average filter to smoothen the ˆ obtained from the non-uniform sampled data. The moving average filter smooths the incoming ˆ by replacing each data point with the average of the neighboring data points defined within a specified span. This process is equivalent to low pass filtering with the response of the smoothing given by the difference equation

$$\gamma s\,(f) = \frac{1}{2M+1}\gamma(f+M) + \gamma(f+M-1) + \cdots + \gamma(f-M) \quad (2)$$

where γs (f) is the smoothed value for the PSD at frequency f, M is the number of neighboring data points on either side of γs (f), and 2M + 1 is the span. Smoothing is done over a span of 2M + 1 is the span where M is the number of neighboring data points on either side of γs (f). Although this process is simple in operation, but we will show later that the results obtained are quite accurate.

C. SUPPORT DETECTOR BLOCK

Once a smooth PSD estimate has been obtained, the spectral support f is computed with reference to a threshold value, η which is selected as a function of maximum PSD value γ s max i.e.

η = [γs max + β] (4) where s is the floor function. If γs is normalized such that ˆmax = 0 dB then $\eta = \beta$ dB where β is negative valued. The selection of parameter β plays an important role in the performance of the proposed method and is further explained in Section VI. With reference to the threshold η, the number of bands N_B are computed. The process is illustrated in Figure 4 for a signal with N_B = 4. The spectral support is calculated using the following equation

$$\cup_{i=1}^{N}[ai, bi] \qquad (3)$$

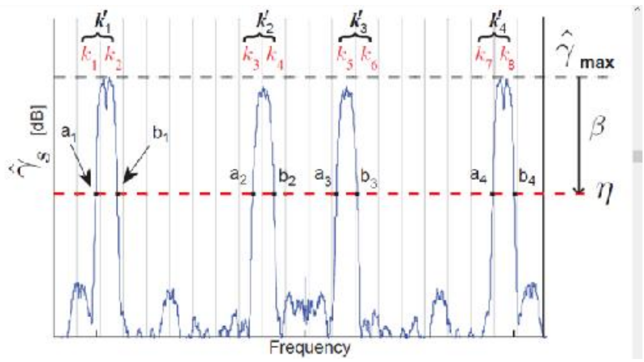

Figure 4. Support detection using threshold in non-uniform spectrum sensing block

D . PERFORMANCE OF THE PROPOSED NON-UNIFORM DETECTOR

In this section, we present some numerical results for our proposed non-uniform spectrum sensing block. For simulations, the wideband of interest is in the range of B =[−300, 300] MHz, therefore, the Nyquist sampling rate is f_{Nyq} = 600 MHz. We consider a multiband signal with NB = 6 bands, each with a maximum bandwidth of 10MHz. Therefore, the input signal is sparse in the frequency domain. For simplicity we assume that the

NB bands have the same amplitude. 16 QAM modulation symbols are used that are corrupted by the additive white Gaussian noise. Given f_{max} = 300 MHz, it is desired to detect NB and K for the input signal which is sampled at a sub-Nyquist sampling rate using the multicoset sampler. For the NUSS block, _ is set equal to -5 dB. Note that _ is the ratio of the number of non-uniform samples to the number of Nyquist rate samples. i.e. the average sampling rate for the multicoset sampler is f_{avg} = _f_{Nyq} = (p/L)f_{Nyq}. The detection performance is evaluated by computing the probability of correctly detecting the signal occupancy in terms of the number of bands NB **.**

CONCLUSION

In this paper, we have proposed a spectrum sensing technique based on non-uniform sub-Nyquist multicoset sampling. We have shown that the proposed sensing model works efficiently and shows high detection and low false alarm probabilities. The performance of the spectrum sensing model improves with increase in number of the non-uniform samples available to the sensing method. Finally, the effect of false detection is shown on the RMSE of the reconstructed time domain signal.

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