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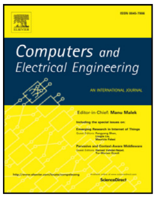

Adaptive non-uniform sampling of sparse signals for Green Cognitive Radio[☆]

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Based on previous results on periodic non-uniform sampling (Multi-Coset) and using the well known Non-Uniform Fourier Transform through Bartlett's method for Power Spectral Density estimation, we propose a new smart sampling scheme named the Dynamic Single Branch Non-uniform Sampler. The idea of our scheme is to reduce the average sampling frequency, the number of samples collected, and consequently the power consumption of the Analog to Digital Converter. In addition to that our proposed method detects the location of the bands in order to adapt the sampling rate. In this paper, through we show simulation results that compared to classical uniform sampler or existing multi-coset based samplers, our proposed sampler, in certain conditions, provides superior performance, in terms of sampling rate or energy consumption. It is not constrained by the inflexibility of hardware circuitry and is easily reconfigurable. We also show the effect of the false detection of active bands on the average sampling rate of our new adaptive non-uniform sub-Nyquist sampler scheme.

1. Introduction

Radio Frequency (RF) allows modulation of narrow band signals with a high carrier frequency. The radio signals of human origin are often sparse. In other words, they are composed of a relatively small number of narrow band transmissions spread across a wide spectral region. A practical description of these signals is the *multi-band* model where the spectrum of the signal is only composed of several continuous intervals in a wide spectrum. In addition, new wireless applications place high demands on the quality of radio resources such as bandwidth and spectrum. Moreover, the current trends in wireless technology have increased the complexity of the receiver, more specifically its Analog to Digital Converter (ADC). According to Shannon–Nyquist theorem, a signal whose spectral support is limited to $-\frac{f_{nyq}}{2}$ and $\frac{f_{nyq}}{2}$ can be perfectly reconstructed by sampling at f_{nyq}. To sample a wide band signal with Nyquist rate will require a high sampling rate ADC which consumes a lot of energy. To reduce the sampling rate, and in turn the energy consumption, several researchers have studied the possibility of sub-Nyquist sampling. In [1], a sub-Nyquist sampling method is proposed for sparse multi-band signals, called Modulated Wideband Converter (MWC). MWC consists of several stages and each stage uses a different mixing function followed by a low pass filter and a low uniform sampling rate. This sampling technique shows that perfect reconstruction

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is possible when the band locations are known. In [1,2], authors have studied the blind case, where the location of the bands is unknown with an inflexible and sub optimal sampler scheme in term of sampling rate. Over the recent years, multi-coset sampling [3–5] has gained fair popularity and several methods of implementing the multi-coset sampling have been proposed. The most famous architecture is composed of several parallel branches, each with a time shift followed by a uniform sampler operating at a sampling rate lower than the Nyquist rate. Recently, a different approach for implementing multi-coset sampling has been proposed in [6], which uses uniform samplers operating at different rates and is known as the Synchronous Mutlirate Sampling. In [7], a Dual-sampling architecture is presented for multi-coset sampling which is basically a subset of the Synchronous Multi rate Sampling and uses only two uniform samplers. But for optimal reconstruction, all these methods assume that the number of bands and the maximum bandwidth, a band can have, is known. In [1], authors have defined some requirements that need to be fulfilled for a sampling system to be efficient. These requirements are stated as follows: the sampling rate (average) should be as low as possible, the system has no prior knowledge of the band locations, and the system can be designed with existing devices. In this paper, we propose a blind sampler based on multi-coset sampling scheme which respects the above stated definition of an efficient sampler. Our scheme estimates the spectral support, using our non-uniform spectrum sensing model proposed in [8,9], to minimize the average sampling rate, thereby reducing the number of samples as well as energy consumption. We show that our proposed spectrum sensing model provides accurate results using less data samples. Its performance is examined at low rate SNR values with less data samples. In addition, its power consumption is compared with regular ADC when the input signal is very sparse and it is found to produce satisfactory results.

This article is organized as follows. In Section 2, we present the signal model along with an overview of multi-coset sampling. In Section 3, we present our proposed sampling system and explain all its blocks. Then the non-uniform spectrum sensing model is presented and the functionality of each block is explained. Numerical results are presented in Section 4 followed by a conclusion in the end.

2. Background

2.1. Multi-band signal model

Let $\mathcal{M}$ ($\mathcal{B}$) be the class of continuous real-valued signals with finite energy and band-limited to a subset $\mathcal{B}$.

$$\mathcal{M}(\mathcal{B}) = \left\{x(t) \in L^2(\mathbb{R}) : \mathbf{X}(f) = 0 \forall f \notin \mathcal{B}\right\} \tag{1}$$

where $\mathcal{B} = [-\frac{f_{nyq}}{2}, \frac{f_{nyq}}{2}]$ and $\mathbf{X}(f) = \int_{-\infty}^{+\infty} x(t)e^{-j2\pi ft}\,dt$ is the Fourier transform of the signal $x(t)$.

Let $\mathcal{F}$ represent the spectral support of the signal defined by

$$\mathcal{F} = \bigcup_{i=1}^{N} [a_i, b_i] \tag{2}$$

where $\mathcal{F} \subset \mathcal{B}$,$a_i$ and b_i represent, respectively, the lower and upper bound of each bands, and N is the number of bands in $\mathcal{B}$.

2.2. Multi-coset sampling

Multi-Coset (MC) sampling is a periodic non-uniform sub-Nyquist sampling technique which samples a signal $x(t)$ at a lower rate than the Nyquist rate, thereby capturing only the amount of information required for an accurate reconstruction of the signal [1,2]. In short, the process of MC 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. The process is repeated for consecutive segments of L uniform samples such that the p selected samples have a sampling period L. The set $\mathcal{C} = \{c_i\}_{i=0}^{p-1}$ specifies the p samples that remain in each segment of length L such that $0 \le c_0 < c_1 < \cdots < c_{p-1} \le L-1$.

MC sampler is usually implemented by placing p ADCs in parallel as shown in Fig. 1. Each ADC operates uniformly at a period $T_s = LT$. The $\Delta_i = c_iT$ represents the time shifts in sampling instants introduced in each branch. It should be noted that a good choice of the sampling pattern $\mathcal{C}$ reduces the margin of error due to spectral aliasing and sensitivity to noise in the reconstruction process [2]. It is quite evident from Fig. 1 that once the sampling parameters (such as p) are selected, architecture of the MC sampler will remain unchanged irrespective of the input signal characteristics. In other words, once designed, the sampler in Fig. 1 cannot be changed because of hardware limitations. If the input signal changes the MC sampler does not adapt, which results in sub-optimal sampling of the signal, as will be show later. This motivated us to look for an flexible system which conforms with the spectrum of the input signal. In the next section, we explain the functionality of our new sampling scheme with and show that it is more flexible compared to the MC sampler in Fig. 1.

3. System model

With the exponential growth in the means of communications, modifying radio devices easily and cost-effectively has become business critical. Software-defined radio (SDR) technology brings the flexibility, cost efficiency and power to drive