APPLICATION OF COMPRESSED SENSING TO WIDEBAND SPECTRUM SENSING IN COGNITIVE RADIO NETWORKS

Michael M. Abdel-Sayed, Ahmed Khattab, Mohamed F. Abu-Elyazeed

EECE Department – Cairo University, Giza, Egypt

ABSTRACT

Wideband spectrum sensing is one of the most challenging aspects of Cognitive Radio Networks (CRNs). It should be performed as fast and as accurate as possible. Traditional wideband spectrum sensing techniques require excessively high sampling rate analog-to-digital converters (ADCs). Compressed sensing was considered to enable wideband spectrum sensing at a much lower sampling rate below the Nyquist rate. However, the reconstruction complexity and speed of existing compressed wideband spectrum sensing remained a barrier for such an application. In this paper, we introduce the Adaptive Reduced-set Matching Pursuit (ARMP) and Fast Matching Pursuit (FMP) which are fast and accurate recovery algorithms for compressed sensing. We apply FMP to wideband spectrum sensing for cognitive radio networks, resulting in a significant complexity reduction at a remarkable accuracy.

1. INTRODUCTION

Fast and accurate spectrum sensing is a main and challenging requirement in CRNs. However, traditional techniques for wideband spectrum sensing suffer from the requirement for ADCs that operate at excessively high sampling rates. Attempting to alleviate such sampling rates, other techniques result in excessively large hardware or time requirements.

Compressed sensing [1], a recently developed sampling technique that acquires data at a much lower rate than the Nyquist rate, has been proposed for application in wideband spectrum sensing. Therefore, ADCs that operate at much lower rates can be used. The optimal solution for reconstructing sparse signals is through ℓ_1 minimization. However, it is computationally expensive and not appropriate for most real-time applications. Several greedy recovery algorithms have been recently developed, which aim to reduce the computational complexity of ℓ_1 minimization, while maintaining a good reconstruction accuracy. However, the reconstruction complexity is still a barrier for such an application.

2. RELATED WORK

In [2] the sparse spectrum signal is reconstructed using the TOMP algorithm. Subsequently, the boundaries between spectrum bands are estimated using a wavelet-based edge detector. The Power Spectral Density (PSD) within each band is estimated and the spectrum holes are identified. In [3], the fact that the spectrum signal is sparse in the Fourier-wavelet packet domain is exploited. ℓ_1 minimization is used for spectrum signal reconstruction, and then the same techniques were used for boundary and PSD estimation as in [2].

3. KEY IDEA

The goal of this work is to perform wideband spectrum sensing for cognitive radio networks as fast and accurately as possible. We develop a fast and accurate greedy recovery algorithm for compressed sensing, Adaptive Reduced-set Matching Pursuit (ARMP) [4, 5]. Its main idea is to select an optimum number of elements from the correlation values per iteration. Then, we develop the Fast Matching Pursuit (FMP) to further improve the reconstruction speed, especially for the reconstruction of signals of larger sizes. The main idea of FMP is to avoid large matrix inversion during signal estimation. Then, we apply FMP in both wavelet and wavelet packet domains to wideband spectrum sensing for cognitive radio networks. We show that FMP results in fast and accurate spectrum estimation that is suitable for real-time CRN applications, in contrast to other techniques that are hindered by larger reconstruction complexity.

4. PROPOSED APPROACH

4.1. Compressed Sensing

Consider a sparse signal $x \in \mathbb{R}^n$, of sparsity level k. A measurement system that samples this signal to acquire m linear measurements is typically modeled as

$$y = \Phi x, \tag{1}$$

where $\Phi \in \mathbb{R}^{m \times n}$ is the sensing or measurement matrix, $y \in \mathbb{R}^m$ is the measurement vector or the samples, and $m \ll n$.

4.2. Adaptive Reduced-set Matching Pursuit

ARMP goal is to reconstruct a sparse signal x from measurements given by (1) as fast and accurately as possible. In order to achieve these goals, *(i)* ARMP iteratively identifies the support of the sparse signal by *adaptively* selecting elements from a *significantly* reduced set of the correlation values. This contrasts with existing algorithms in which the selection is performed from the whole correlation vector and is performed in a non-adaptive manner in the majority of existing algorithms. *(ii)* ARMP estimates the sparse signal based on the identified support set. *(iii)* ARMP uses pruning to exclude the incorrectly selected elements, and hence, prevent such erroneous selections from degrading the performance. *(iv)* A residual is then calculated by removing the estimated part from the measurement vector. These steps are repeated until a stopping criterion is met.

4.3. Fast Matching Pursuit (FMP)

FMP is a faster recovery algorithm for compressed sensing. Its main goal is to reconstruct a sparse signal, as fast and accurately as possible, especially when operating with data of larger sizes. This makes it suitable for a wide range of applications including CRN applications. The FMP algorithm is composed of the following components: *(i)* support identification, *(ii)* signal estimation, *(iii)* pruning, and *(iv)* residual calculation. FMP follows the same selection strategy as ARMP. The signal is then estimated based on this support, through least square minimization. In FMP, least square minimization is performed iteratively avoiding large matrix inversion, which results in significant complexity reduction. Instead of forming the pseudo-inverse required for least square minimization directly with matrix inversion, FMP calculates it in each iteration from data in the previous iteration. FMP then prunes the signal estimate to exclude the incorrectly selected elements. Then a residual is calculated and the aforementioned steps are repeated until a stopping condition is met.

4.4. PSD Estimation

In case the band boundary locations are unknown, the boundaries are obtained as the local maxima of the wavelet modulus. Then the PSD within each band can be simply estimated by averaging the samples within each band, since the spectrum signal is constant within each band.

5. SIMULATION RESULTS

We compare the performance of FMP for wideband spectrum sensing against the two techniques proposed in [2] and [3], which use ℓ_1 minimization in wavelet packet domain, and TOMP in wavelet domain, respectively. Table 1 presents a comparison of the reconstruction time required by the simulated algorithms, where W stands for wavelet domain and WP stands for wavelet packet domain. We compare the algorithms against the number of occupied bands. The Receiver Operating Characteristic (ROC) curves for the simulated algorithms is given in Fig. 1. ℓ_1 minimization gives the best performance, closely followed by FMP in wavelet packed domain, and wavelet domain.

Other results show that our proposed algorithm is capable of reconstructing spectrum signals from samples at a rate of about 25% of the Nyquist rate, significantly faster than other related algorithms, at about 99% probability of detection and about 1% probability of false alarm.

Table 1. Reconstruction time in seconds

Occupied Bands	10	20	30	40	50	60	70	80	90
L1 Norm WP	18.8	26.5	44.7	98.0	87.9	85.7	77.6	87.0	69.5
TOMP W	1.0	1.3	1.1	1.3	1.3	1.4	1.1	1.3	1.4
FMP W	0.0	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3
FMP WP	0.0	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3

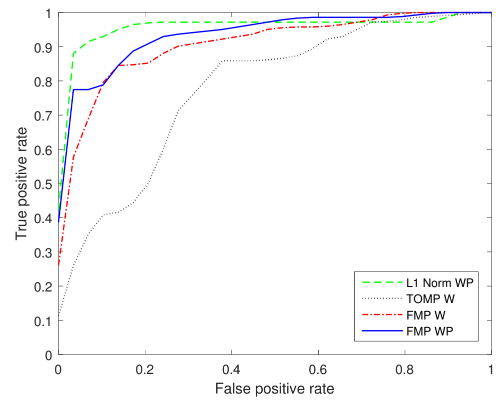

Fig. 1. ROC Curves of different approaches.

6. CONCLUSIONS

The main contributions of this research are as follows. We have developed the ARMP and FMP algorithms that achieve significant complexity reduction with high reconstruction accuracy compared to related algorithms. We have applied FMP to wideband spectrum sensing to demonstrate its superiority compared to ℓ_1 minimization or TOMP in terms of accuracy and low complexity.

7. REFERENCES

[1] D. L. Donoho, "Compressed sensing," *IEEE Trans. on Information Theory*, vol. 52, no. 4, pp. 1289–1306, 2006.

[2] Z. Tian and G. B. Giannakis, "Compressed sensing for wideband cognitive radios," in *IEEE ICASSP*, 2007.

[3] H. E. Egilmez and A. Ortega, "Wavelet-based compressed spectrum sensing for cognitive radio wireless networks," in *IEEE ICASSP*, 2015.

[4] M. M. Abdel-Sayed, A. Khattab, and M. F. Abu-Elyazeed, "Adaptive reduced-set matching pursuit for compressed sensing recovery," in *IEEE ICIP*, 2016.

[5] ——, "RMP: Reduced-set matching pursuit approach for efficient compressed sensing signal reconstruction," *Journal of Advanced Research, Elsevier*, vol. 7, no. 6, pp. 851–861, 2016.