

A fast sensing algorithm for spectrum detection in cognitive radios

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To my parents and teachers

Abstract

Cognitive Radio (CR) has emerged as a very promising solution to mitigate the scarcity in electromagnetic spectrum for wireless communication. CR promises to maximize the efficiency of spectrum utilization by seeking out spectral vacancies (holes) in the licensed band and using it for communication purposes. Thus sensing of the spectrum to detect the vacant holes forms an integral part of a CR system.

The performance of a cognitive radio system depends on how well it can maximize the usage of a vacant frequency band without causing any interference to the licensed user, also called the primary user. Thus the ability to detect a primary user as well as to avoid any false alarm is of paramount importance for such a system. There are various techniques to examine the presence of a communication signal in a given frequency band. The easiest and most widespread of these is the energy based detection. In this technique, the energy of the received samples is computed and compared with a predetermined threshold. If the total energy of the received samples is more than the computed threshold, the frequency band is assumed to be occupied by the licensed user.

The selection of the threshold to discriminate between the binary hypothesis of presence and absence of primary user signal plays a very vital role in determining the accuracy of the spectrum sensing algorithms. Conventionally, for an energy detector (ED) based CR, the threshold is set based on estimated noise power and this is not changed even though the CR may have more information available about the channel. It has been observed that for a conventional energy detector based CR at low signal-to-noise ratio (SNR), when the time to sense the spectrum is short, the ability to detect the presence of the primary user deteriorates significantly. However, if the threshold is chosen based on the target probability of detection, then there is a significant improvement in the ability of the CR to detect the presence of the primary user. Also the energy detector based CR suffers from the fundamental limitation in that the threshold is a function of the estimate of the noise variance. Any error in the estimation of the noise variance can lead the ED to hit a lower bound for the signal to noise ratio below which the ED cannot detect the signal.

The first contribution of this thesis is an investigation into an adaptive setting of the threshold which takes into account the ever changing channel condition. A study on the effect of low SNR and short sensing time on the probability of detection and probability of false alarm is presented in this thesis. The required number of samples and the desired SNR for meeting the target

performance has been simulated and validated. Also the effect of uncertainties in the estimation of noise power on the performance of an ED and the minimum SNR required guaranteeing the intended performance metrics has been studied in this thesis.

Though the ED has known limitation in the presence of uncertain noise power, it is the simplest detector to design and implement. Also the probability of false alarm of the ED remains low even at low SNRs. To mitigate the disadvantage in the detection probability of the ED, this thesis investigates a two-stage detector for spectrum sensing. Not only can this approach be used to mitigate the disadvantages of a single stage detection technique, but it can also be used to synergize the advantages offered by the individual methods. However, a two-stage analysis increases the time taken to sense the spectrum and arrive at a conclusive result.

As a second contribution of this thesis, an algorithm which can be used to minimize the time taken by a two-stage detector has been proposed. The second stage uses a pilot assisted cyclostationary feature detection technique because of its robustness to noise and better performance at low SNRs. The usage of known pilot in the PU signal has been done to aid in faster detection of the cyclic frequencies. Simulation results have been used to show that the proposed algorithm leads to a larger savings in time as compared to an existing two-stage detection algorithm. The time saved increases as spectrum utilization of the band under consideration becomes sparser. A hardware implementation of the two-stage algorithm has also been presented to quantify the area and power consumption values.

Further the thesis presents a study on the real world signals captured using an universal software radio peripheral 2 (USRP2) board. A GNU radio framework was used to interface with the USRP2 board. This setup was used to sense GSM Mobile signals and signals generated from a signal generator. The spectrum of the captured signals showed the difficulties in estimation of the noise floor and how an error in estimation of the noise variance can make an ED based CR non functional in a practical scenario when the signal power is low.

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List of Abbreviations

AIC	Akaike Information Criterion
ADC	Analog to Digital Converter
ATSC	Advanced Television Systems Committee
AWGN	Additive White Gaussian Noise
CAF	Cyclic Autocorrelation Function
CDMA	Code Division Multiple Access
CDR	Constant Detection Rate
CFAR	Constant False Alarm Rate
CFD	Cyclostationary Feature Detector
CPM	Central Processing Module
CR	Cognitive Radio
CSD	Cyclic Spectral Density
DAC	Digital to Analog Converter
DAD	Distribution Analysis Detector
DAM	Data Acquisition Module
DSSS	Direct Sequence Spread Spectrum
DDC	Digital Down Converter
ED	Energy Detector
EEPROM	Electrically Erasable Programmable Read Only Memory
EME	Energy with Minimum Eigen value
EVD	Eigen Value Detector
FAM	Fast Fourier Transform based Accumulation Method
FCC	Federal Communications Commission
FFT	Fast Fourier Transform

FPGA	Field Programmable Gate Array
GRC	GNU Radio Companion
GSM	Global System for Mobile communication
I & Q	In-phase and Quadrature
IF	Intermediate Frequency
ISM	Industrial Scientific and Medical
MED	Maximum Eigen value Detector
MF	Matched Filter
MIMO	Multiple Input Multiple Output
MME	Maximum-Minimum Eigen value
MMI	Man Machine Interface
NTIA	National Telecommunication and Information Administration
NTSC	National Television and Systems Committee
OFDM	Orthogonal Frequency Division Multiplexing
PACD	Pilot Assisted Cyclostationary feature Detection
PC	Personal Computer
PSD	Power Spectral Density
PU	Primary User
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RMT	Random Matrix Theory
ROC	Receiver Operating Characteristics
SD	Secure Digital
SDR	Software Defined Radio
SNR	Signal to Noise Ratio

SSCA	Strip Spectral Correlation Method
SU	Secondary User
SWIG	Simple Wrapper and Interface Generator
TETRA	Terrestrial Trunked Radio
UHD	Universal Hardware Driver
USB	Universal Serial Bus
USRP2	Universal Serial Radio Peripheral2
UWB	Ultra Wide Band
VHF	Very High Frequency
WLAN	Wireless Local Area Network

Publications

International Journal

[1] **Prashob Nair**, A. P. Vinod, Smitha K.G., and Anoop Kumar Krishna, "Fast two-stage spectrum detector for cognitive radios in uncertain noise channels," *IET Communications*, Accepted in February 2012.

International Conferences

[1] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna, "A fast two stage detector for spectrum sensing in cognitive radios," *IEEE International Conference on Vehicular Technology*, September 2011, San Francisco, USA.

[2] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna , "An energy detector for cognitive radios in channels at low SNR using adaptive threshold," *IEEE International Conference on Information, Communications and Signal Processing*, December 2011, Singapore .

[3] **Prashob Nair**, A. P. Vinod, and Anoop Kumar Krishna, "An adaptive threshold based energy detector for spectrum sensing in cognitive radios at low SNR," *IEEE International Conference on Communication Systems (ICCS)*, pp. 574-578, November 2010, Singapore.

[4] Smitha K.G., A. P. Vinod, and **Prashob Nair**, "Low power DFT filter bank based two-stage spectrum sensing," *8th International Conference on Innovations in Information Technology*, Al Ain, United Arab Emirates, March 2012 (Accepted).