Chapter 23

Complexity Issues within Eigenvalue–Based Multi–Antenna Spectrum Sensing

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ABSTRACT

This chapter provides a deep insight into multiple antenna eigenvalue-based spectrum sensing algorithms from a complexity perspective. A review of eigenvalue-based spectrum-sensing algorithms is provided. The chapter presents a finite computational complexity analysis in terms of Floating Point Operations (flop) and a comparison of the Maximum-to-Minimum Eigenvalue (MME) detector and a simplified variant of the Multiple Beam forming detector as well as the Approximated MME method. Constant False Alarm Performances (CFAR) are presented to emphasize the complexity-reliability tradeoff within the spectrum-sensing problem, given the strong requirements on the sensing duration and the detection performance.

INTRODUCTION

Spectrum sensing is a key capability to allow a reliable overlay dynamic spectrum access where the unlicensed Cognitive Radio (CR) users, known as secondary users (SUs), can only use frequency resources that are temporarily not used by licensed users, known as primary users (PUs). To avoid unwanted collision with PUs, SUs are required to perform fast and accurate spectrum sensing. For example, the IEEE 802.22 standard, which is the first worldwide CR standard operating within unused TV channels, specifies functional sensing requirements, where incumbent PU signals are analog TV, digital TV and wireless microphone signals. Considering ATSC digital TV, which is the digital TV standard adopted

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in North America, the detection time should not exceed 2s and the sensing detection threshold to meet 0.9 probability of detection ($P_d$) and 0.1 probability of false alarm ($P_{fa}$) using an omnidirectional receive antenna with a gain of 0dBi, is -114dBm (IEEE Std 802.22-2011, 2011). For conventional digital TV reception, the ATSC digital TV standard, recommends -83dBm as minimum input RF signal level corresponding to the worst conditions for a digital TV receiver to display a “viewable” picture (ATSC Std, 2010). Obviously, as standardized by IEEE 802.22, SUs operating in TV white channels should be able to detect digital TV signal at a very low SNR. According to IEEE 802.22 taxonomy, which is of common use, a spectrum sensing techniques could be blind or signal specific, coarse or fine. Blind techniques, as opposed to signal specific, do not rely upon a specific feature of the considered incumbent signal type (e.g. ATSC pilot sensing). Energy detector, eigenvalue based sensing techniques and multi-resolution sensing techniques are classified as blind sensing techniques. Coarse sensing techniques do not meet IEEE 802.22 sensing requirements but may still be useful for detecting strong signals in a shorter period of time than fine sensing techniques. For example, eigenvalue based sensing technique is a coarse sensing techniques for DTV detection but it meets the fine sensing requirements for wireless microphones. Furthermore, all IEEE 802.22 recommended ATSC specific sensing techniques are coarse.

This reveals that developing a blind and fine sensing technique is a challenging issue. Indeed, practical implementation of sensing techniques, meeting sensing requirements in terms of detection time and reliability, raises two main issues: number of required samples and computational complexity. While minimizing the observation window has been the main focus of spectrum sensing contributions in the research literature, computational complexity has not been carefully studied. Very few works consider the evaluation of the computational cost of their proposed techniques and when provided, an asymptotic evaluation is typically given using the “big-Oh” notation. Paradoxically, this is meaningless, as spectrum sensing techniques are practically implemented using finite and relatively small system parameters. In this chapter, the focus is on the complexity of eigenvalue based spectrum sensing techniques. An exact evaluation of the computational cost in terms of floating point operation ($flop$) number is provided.

**BACKGROUND**

In the literature on spectrum sensing, energy detection is considered as the simplest sensing technique. It is the optimum detector given exact knowledge of the noise power. Practically, a small noise uncertainty results in a huge degradation of its performances. Assuming temporally uncorrelated noise, covariance and eigenvalue based sensing techniques were proposed in the time domain to provide robustness towards noise uncertainty (Zeng & Liang, 2009a, 2009b). Motivated by the known and simple structure of the received signal covariance matrix, these techniques are intuitive, sub-optimal and ad-hoc. The more popular is the Maximum to Minimum Eigenvalue (MME) detector. More recently, there has been an extensive literature on multiple antenna spectrum sensing (Zhang, Liang & Zeng 2010). Basically, multiple antennas allow multiplying the number of received samples within a certain observation window. Furthermore, receive diversity introduced by an antenna array at the reception, holds a great potential to enhance traditional spectrum sensing techniques through various combining scheme (Pandharipande & Linnartz 2007) and to provide new spectrum sensing techniques. Surprisingly, the generalized likelihood test derivation, assuming spatially uncorrelated noise, gives rise to eigenvalue based sensing. Eigenvalue based techniques have been intensively studied in the literature from the perspective of derivation of a closed-form expression of the probability of false alarm. Actually, this is fundamental to tune the
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