Expert Systems with Applications 40 (2013) 2165–2173

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

The performance evaluation of a spectrum sensing implementation using an automatic modulation classification detection method with a Universal Software Radio Peripheral

Jide Julius Popoola *, Rex van Olst [1]

Centre for Telecommunications Access and Services, School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, South Africa

ARTICLE INFO

Keywords:
Spectrum holes
Cognitive radio
Hierarchical access model
Spectrum sensing techniques
Performance evaluation metrics

ABSTRACT

Based on the inherent capability of automatic modulation classification (AMC), a new spectrum sensing method is proposed in this paper that can detect all forms of primary users' signals in a cognitive radio environment. The study presented in this paper focuses on the sensing of some combined analog and digitally primary modulated signals. In achieving this objective, a combined analog and digital automatic modulation classifier was developed using an artificial neural network (ANN). The ANN classifier was combined with a GNU Radio and Universal Software Radio Peripheral version 2 (USRP2) to develop the Cognitive Radio Engine (CRE) for detecting primary users' signals in a cognitive radio environment. The detailed information on the development and performance of the CRE are presented in this paper. The performance evaluation of the developed CRE shows that the engine can reliably detect all the primary modulated signals considered. Comparative performance evaluation carried out on the detection method presented in this paper shows that the proposed detection method performs favorably against the energy detection method currently acclaimed the best detection method. The study results reveal that a single detection method that can reliably detect all forms of primary radio signals in a cognitive radio environment, can only be developed if a feature common to all radio signals is used in its development rather than using features that are peculiar to certain signal types only.

1. Introduction

Under the current fixed radio spectrum allocation policy, radio spectrum licensed owners or users normally pay to have exclusive access to certain portion of the spectrum. This policy has served well in the past especially in preventing interference amongst radio spectrum users. However, over the last two decades, as the world experiences proliferation of wireless services and applications, coupled with the increase in demand for and use of radio spectrum, a fixed frequency allocation policy has been observed as a major cause of radio spectrum scarcity. This stemmed from the imbalance the policy has created between radio spectrum scarcity and radio spectrum underutilization as a significant amount of licensed radio spectrum is sporadically used by licensed owners (Popoola & van Olst, 2011). This underutilization of radio spectrum is not limited to certain nations of the world or frequency ranges but cuts across all nations, developed and developing, as well as different frequency ranges. This is revealed by a series of actual radio spectrum usage profiles carried out by different researchers in different parts of the world, at different frequency ranges.

For instance, a typical radio spectrum measurement carried out by the Enforcement Bureau of Federal Communications Commission (FCC) at Atlanta, Chicago and other parts of the United States, as reported by Liu, Li, and Zhou (2010), shows that only 5–10% of the licensed spectrum is used on average. In a similar measurement carried out by Defence Advance Research Projects Agency (DARPA), which was reported by Gandetto and Regazzoni (2007) reveals that only 2% of the licensed spectrum is in use in the US at any given moment. Similar actual spectrum usage measurements of the 790–862 MHz licensed spectrum carried out in Port Elizabeth, Johannesburg, Bloemfontein, Durban, Cape Town and Pretoria in South Africa by the Independent Communications Authority of South Africa (ICASA) in March 2009 revealed that 99.74%, 99.84%, 99.97%, 98.58%, 98.59% and 99.36% are the percentages of inactive frequencies respectively in those locations (Dana, 2010a). A similar actual measurement also carried out in 2010 for 450–470 MHz by ICASA in Port Elizabeth, Johannesburg, Bloemfontein, Durban and Cape Town showed that 0.37%, 2.0%, 1.75%, 0.81%, 0.67% and 0.67% are the respective percentages of the active

* Corresponding author. Address: Department of Electrical and Electronics Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure, Nigeria. Tel.: +234 803 413 1860.

E-mail addresses: jidejulius2001@gmail.com (J.J. Popoola), Rex.VanOlst@wits.ac.za (R. van Olst).

[1] Tel.: +27 82 449 2384; fax: +27 11 403 1929.

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.10.047

licensed frequencies in those locations at any time (Dana, 2010b). These series of measurements show that scarcity of usable radio frequencies for wireless communications is not as a result of a lack of radio spectrum but more likely as a result of the current inefficient fixed radio spectrum allocation policy.

An effort to alleviate the radio spectrum scarcity as well as ameliorating radio spectrum underutilization therefore brings about the idea of communications systems that can exploit the unused portions of the licensed spectrum also known as the "spectrum holes". The radio technology that has this capability is known as Cognitive Radio (CR). CR is a radio system that can adaptively and dynamically allow users to access radio spectrum in an opportunistic manner by switching amongst unused portions of the licensed spectrum or spectrum holes at different time intervals. This idea of an opportunistic access strategy can be categorized under three broad models: dynamic exclusive use model, open sharing model, and hierarchical access model (Zhao & Sadler, 2007). In this paper, we focus on the hierarchical access model with primary and secondary users. The basic idea of this model is to open licensed spectrum to unlicensed or secondary users without interfering with the licensed or primary user of the spectrum.

Under the hierarchical access model, two spectrum access strategies for sharing the radio spectrum between the primary and secondary users have been proposed; spectrum underlay and spectrum overlay. In a spectrum underlay access strategy, concurrent transmission in the manner of an Ultra-Wide Band (UWB) system by both primary and secondary users is allowed. However, this secondary spectrum access strategy protects the primary users by enforcing a spectral mask on the secondary signals so that the interference generated by the secondary users is below the acceptable noise floor for the primary users of the spectrum. Hence in such systems, the unlicensed or secondary user can always access the spectrum subject to the interference threshold constraint. However, satisfying the interference constraint is technically challenging (Khoshkholgh, Navaie, & Yanikomeroglu, 2010) since the interference power constraints associated with an underlay access strategy only allows short range communications (Srinivasa & Jafar, 2007). In addition, in underlay spectrum sharing, the unlicensed user must satisfy the interference threshold condition even when the licensed or primary user is idle. During this idle period, fulfilling the interference constraint limits pertaining to the transmission power of the unlicensed user reduces its achievable transmission capability. More so, in an underlay access strategy, the achievable capability of the unlicensed user is further reduced during the busy periods of the licensed user because of the interference imposed by the licensed user activity at the unlicensed user's receiver. To tackle these aforementioned issues, overlay spectrum sharing was proposed.

In overlay spectrum sharing, access to the spectrum is based on the idea of opportunistic communication, whereby the unlicensed user only accesses the licensed spectrum whenever the licensed user is idle and leaves the channel before the licensed user reappears on the channel. This access strategy requires that the unlicensed user senses the spectrum to ascertain the absence/presence/reappearance of the licensed user so as not to cause interference to the licensed user. Whenever the licensed user reappears on the channel, the unlicensed user is expected to stop transmission and vacate the channel immediately. In order word, this spectrum access sharing strategy is permitted only in temporal frequency voids, referred to as spectrum holes or white space, that are not in use by the licensed owners. This spectrum access strategy is often called Opportunistic Spectrum Access (OSA) or Dynamic Spectrum Access (DSA) (Chen, Park, & Reed, 2008).

Cognitive Radio (CR) (Haykin, 2005), as earlier mentioned, is the enabling technology for DSA. Unlike a traditional radio, a CR has the capability to sense and understand its environment and proactively change its mode of operation as needed (Chen et al., 2008). Generally, as a secondary user of already allocated spectrum, the fundamental requirement of the CR is to avoid interference to the primary users in their vicinity (Cabric, Tkachenko, & Brodersen, 2006). Therefore, spectrum sensing has been identified as a key enabling functionality to ensure that a CR does not interfere with primary users by reliably detecting primary users' signals. In addition, reliable spectrum sensing plays a critical role on communication links of CR since it creates spectrum opportunities for them. Generally, CR carries out spectrum sensing with twofold objectives; to identify sub-bands of the radio spectrum that are underutilized by the primary users, and to provide the means for making those bands available for transmission by unlicensed secondary users.

The main challenge for a CR is how to reliably detect the presence of the licensed or primary user (PU) in order to prevent interference to the PU. Currently, the search for spectrum holes is based on different spectrum detection techniques. The five most common detection techniques usually employed in spectrum hole detection are matched-filtering detection, energy detection, cyclostationary detection, wavelet detection, and compressed detection techniques. However, analyses of these detection methods or techniques show that there is currently no single detection method that can reliably sense and detect all forms of primary radio signals in a cognitive radio environment (Popoola & van Olst, 2011). Finding a single detection method that can sense and detect all forms of primary radio signals underlie the study presented in this paper. The remainder of the paper is organized as follows: In Section 2 we present a brief review of the five common detection techniques mentioned above with emphasis on their strengths and weaknesses. Thereafter, we introduce our novel signal detection method. In Section 3 we present the methodology involved in developing our proposed detection method. Detailed information on the development of our CRE is also provided in this section. Section 4 focuses on the performance evaluation of our proposed detection method. The detection probability of our detection method was compared against energy detection method, which is currently the best acclaimed detection method. The paper is concluded in Section 5 with a summary of our findings.

2. Brief review of conventional spectrum sensing and detection methods

As a result of the importance of spectrum sensing to prevent secondary users from interfering with the primary user, spectrum sensing has become a very active research area in the last decade. Quite a few spectrum sensing methods have been proposed, including Energy Detection (ED) (Lataief & Zhang, 2009; Sahai & Cabric, 2005), Matched-Filter Detection (MFD) (Chen, Gao, & Daut, 2007; Sahai & Cabric, 2005), Cyclostationary Feature Detection (CFD) (Akyildz, Lee, Vuran, & Mohanty, 2006; Akyildz, Lo, & Balakrishnan, 2011; Malik et al., 2010) and some newly emerging methods such as Wavelet-Based Detection (WBD) (Ma, Li, & Juang, 2009; Tian & Giannakis, 2006) and Compressed Sensing Detection (CSD) (Candes, Romberg, & Tao, 2006; Donoho, 2006). These spectrum sensing methods have different requirements for their implementation and accordingly can be classified into four general categories:

(i) Methods require *a priori* information of the primary user;
(ii) Methods require no *a priori* information or knowledge about the primary signal;
(iii) Methods that can sense narrowband primary signals; and
(iv) Methods that can sense broadband primary signals.

Based on these classifications, for example, MFD and CFD belong to category (i); ED, WBD and CSD belong to category (ii); MF, CFD and ED methods belong to category (iii); while ED, WBD