AN INNOVATIVE SIGNAL DETECTION ALGORITHM IN FACILITATING THE COGNITIVE RADIO FUNCTIONALITY FOR WIRELESS REGIONAL AREA NETWORK USING SINGULAR VALUE DECOMPOSITION

MOHD. HASBULLAH BIN OMAR

DOCTOR OF PHILOSOPHY

UNIVERSITI UTARA MALAYSIA

2011

The contents of the thesis is for internal user only

Awang Had Salleh Graduate School of Arts and Sciences
UUM CAS
Engaging Minds for a Better Tomorrow

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

MOHD HASBULLAH OMAR

calon untuk Ijazah
(candidate for the degree of) PhD

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title):

"AN INNOVATIVE SIGNAL DETECTION ALGORITHM IN FACILITATING THE COGNITIVE RADIO FUNCTIONALITY FOR WIRELESS REGIONAL AREA NETWORK USING SINGULAR VALUE DECOMPOSITION"

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada : ***15 September 2011.***
That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on: ***September 15, 2011.***

Pengerusi Viva: *(Chairman for VIVA)*	**Assoc. Prof. Dr. Huda Hj Ibrahim**	Tandatangan *(Signature)*
Pemeriksa Luar: *(External Examiner)*	**Prof. Dr. Tharek Abdul Rahman**	Tandatangan *(Signature)*
Pemeriksa Luar: *(External Examiner)*	**Assoc. Prof. Dr. Hj. Mazani Hj Manaf**	Tandatangan *(Signature)*
Nama Penyelia/Penyelia-penyelia: *(Name of Supervisor/Supervisors)*	**Assoc. Prof. Dr. Suhaidi Hassan**	Tandatangan *(Signature)*

Tarikh:
(Date) ***September 15, 2011***

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to :

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUM College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok

Abstrak

Tesis ini memperkenalkan algoritma pengesan isyarat yang inovatif dalam memudahkan fungsi radio kognitif untuk piawaian IEEE 802.22 Rangkaian Tanpa Wayar Kawasan Serantau (WRAN) yang baharu. Ia adalah sejenis pengesan isyarat yang berdasarkan teknik Penguraian Nilai Singular (SVD) yang menggunakan nilai eigen daripada isyarat yang diterima. Penyelidikan ini bermula dengan sorotan terhadap kaedah pengesanan spektrum semasa yang mana penyelidikan ini telah mengklasifikasikan kepada pengesan isyarat tertentu, separa kenal atau tak kenal. Salah satu pengesan isyarat tak kenal dikenali sebagai pengesanan berasaskan nilai eigen telah didapati merupakan sejenis pengesan yang paling diminati kerana keupayaannya dalam pengesanan, masa pelaksanaan, dan sifar-keutamaan pengetahuan. Algoritma pengesanan telah dibangunkan secara analitis dengan menggunakan Teori Pengesanan Isyarat (SDT) dan Teori Matrik Rawak (RMT). Ia kemudiannya disimulasikan menggunakan perisian Matlab® bagi menguji prestasi dan dibandingkan dengan pengesan isyarat yang juga berasaskan nilai eigen. Walaupun, terdapat beberapa teknik dalam mencari nilai eigen, kajian ini telah mempertimbangkan dua teknik yang dikenali sebagai penguraian nilai eigen (EVD) dan SVD. Penyelidikan in telah menguji algoritma yang dibangunkan dengan isyarat yang dijana secara rawak, isyarat simulasi daripada piawaian *Digital Video Broadcasting-Terrestrial* (DVB-T) dan isyarat sebenar televisyen digital yang diukur berdasarkan piawaian *Advanced Television Systems Committee* (ATSC). Pengesan isyarat berasaskan SVD telah didapati lebih cekap dalam mengesan isyarat tanpa mengetahui ciri-ciri isyarat yang dihantar. Algoritma ini sesuai untuk mengesan spektrum dalam klasifikasi tak kenal di mana ciri-ciri isyarat yang hendak dikesan tidak diketahui. Ini juga merupakan kelebihan algoritma ini kerana apa-apa isyarat lain akan mengganggu dan seterusnya menjejaskan kualiti perkhidmatan (QoS) dalam perhubungan piawaian IEEE 802.22. Selain itu, algoritma ini juga menunjukkan prestasi lebih baik dalam persekitaran nisbah isyarat-kepada-hingar (SNR) yang rendah. Untuk menggunakan algoritma tersebut dengan berkesan, pengguna perlu memberikan keutamaan di antara ketepatan pengesanan dan masa pelaksanaan. Daripada dapatan kajian, didapati bahawa bilangan sampel yang lebih tinggi akan memberikan pengesanan yang lebih tepat, tetapi akan mengambil masa yang lebih lama. Namun, bilangan sampel yang sedikit akan menyebabkan pengesanan yang kurang tepat, tetapi masa pelaksanaan akan lebih cepat. Sumbangan tesis ini akan membantu kumpulan kerja piawaian IEEE 802.22, badan-badan yang mengawal selia penggunaan spektrum, operator rangkaian dan pengguna akhir dalam membawa akses jalur lebar ke kawasan luar bandar.

Kata kunci: radio kognitif, rangkaian tanpa wayar kawasan serantau, pengesanan isyarat, televisyen digital, penguraian nilai singular, nilai eigen.

Abstract

This thesis introduces an innovative signal detector algorithm in facilitating the cognitive radio functionality for the new IEEE 802.22 Wireless Regional Area Networks (WRAN) standard. It is a signal detector based on a Singular Value Decomposition (SVD) technique that utilizes the eigenvalue of a received signal. The research started with a review of the current spectrum sensing methods which the research classifies as the specific, semiblind or blind signal detector. A blind signal detector, which is known as eigenvalue based detection, was found to be the most desired detector for its detection capabilities, time of execution, and zero a-priori knowledge. The detection algorithm was developed analytically by applying the Signal Detection Theory (SDT) and the Random Matrix Theory (RMT). It was then simulated using Matlab® to test its performance and compared with similar eigenvalue based signal detector. There are several techniques in finding eigenvalues. However, this research considered two techniques known as eigenvalue decomposition (EVD) and SVD. The research tested the algorithm with a randomly generated signal, simulated Digital Video Broadcasting-Terrestrial (DVB-T) standard and real captured digital television signals based on the Advanced Television Systems Committee (ATSC) standard. The SVD based signal detector was found to be more efficient in detecting signals without knowing the properties of the transmitted signal. The algorithm is suitable for the blind spectrum sensing where the properties of the signal to be detected are unknown. This is also the advantage of the algorithm since any signal would interfere and subsequently affect the quality of service (QoS) of the IEEE 802.22 connection. Furthermore, the algorithm performed better in the low signal-to-noise ratio (SNR) environment. In order to use the algorithm effectively, users need to balance between detection accuracy and execution time. It was found that a higher number of samples would lead to more accurate detection, but will take longer time. In contrary, fewer numbers of samples used would result in less accuracy, but faster execution time. The contributions of this thesis are expected to assist the IEEE 802.22 Standard Working Group, regulatory bodies, network operators and end-users in bringing broadband access to the rural areas.

Keywords: cognitive radio, wireless regional area networks, signal detector, digital television, singular value decomposition, eigenvalue.

Acknowledgement

In the name of ALLAH, Most Gracious, Most Merciful.

There are so many wonderful and talented people whom I would like to thank for their help and patience that I am loss to where to begin.

I will start by thanking my supervisor Associate Professor Dr. Suhaidi Hassan for his help, motivation, and encouragement throughout my study. Dr. Suhaidi is an extremely talented person, and I have nothing but respect and admiration for him. He has helped me immensely, and I would like him to know that I appreciate all of his effort and support.

I would like to take this opportunity to thank Ministry of Higher Education Malaysia for their scholarship support through my studies and to my employer Universiti Utara Malaysia for having trust in me to complete this study. I also would like to extend my gratitude to Malaysian Communication and Multimedia Commission (MCMC) for accepting me for attachment for 18 months at the Spectrum Research and Planning Department (SRPD). Thanks to the former chairman, Datuk Dr. Halim Shafie, the Head of Division, Mr. Toh Swee Hoe, the Head of Department, Tuan Haji Mohd. Zaki Yusuf and all my colleagues, especially Mohd. Redza Fahlawi Mohd Abdullah, Ahmad Nasruddin Atiqullah Fakrullah, Syed Khairulazrin Syed Khairuldin, Shamsul Najib Mohtar, Rafeeza Rahim, Noor Saidatul Aina Ismail, and the rest of the department members. I also would like to thank the Research Collaboration Panel headed by Professor Ir. Dr. Ahmad Faizal Mohd. Zain for allowing me to be in the secretariat to monitor the research grant given by the MCMC to researchers from local universities in the area of spectrum management. It is an honor to have worked with prestigious professors from various universities in Malaysia.

I would like to extend my appreciation to Dr. Apurva N. Mody, the Chairman of the IEEE 802.22 Working Group on Wireless Regional Area Networks, who has helped me in getting the draft standard version 3.0 which is not publicly available. I would also like to thank Professor Dr. El-Mostafa Kalmoun and Dr. Suzilah Ismail from Quantitative Science which I consulted regarding the SVD technique and statistical issues, respectively. Thanks to Dr. Mohamed M. Kadhum, Dr. Angela Amphawan, Dr. Massudi Mahmuddin, and Dr. Osman Ghazali for their input about various aspects of simulation and thesis organization.

I also have to say a huge thank you to all my friends in InterNetWorks Research Group, who kept me sane throughout my PhD and who ensured that I play just as hard, if not harder, then I worked. Special thanks particularly to Ahmad Suki Che Mohamed Arif, Shahrudin Awang Nor and Ahmad Hanis Mohd. Shabli for coming to the operation room for the series of discourse we had.

Finally, my heartiest gratitude goes to my family, to my late father who passed away toward the end of my studies, to my mother who always has faith in me and prays for my success, to my parents-in-law, who are willing to extend a helping hand, to my beloved wife Juliana Aida Abu Bakar for her understanding, support, and love while at the same time also pursuing her PhD, and last but not least to all my children, Ahmad Fathi, Fatimah Azzahraa, Ammar Haseef and Haidatul Alimah for being so sweet and loving.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

3G	-	Third Generation Mobile Telecommunications
ACMA	-	Australian Communication Media Authority
ADC	-	Analog-to-Digital Converter
ATSC	-	Advanced Television Systems Committee
AUC	-	Area Under the Curve
AWGN	-	Additive White Gaussian Noise
BARD	-	Broadband Adaptive Receiver Design
BCED	-	Blindly Combined Energy Detection
BERG	-	Blind Equalization Research Group
BN	-	Base Node
BS	-	Base Station
CDF	-	Cumulative Distribution Function
CN	-	Cognitive Network
COFDM	-	Coded Orthogonal Frequency-Division Multiplexing
CPE	-	Customer-Premises Equipment
CR	-	Cognitive Radio
CS	-	Cosine-Sine
CSD	-	Cyclostationary Based Detector
CSFAR	-	Constant False Alarm Rate
DAC	-	Digital-to-Analog Converter
DFS	-	Dynamic Frequency Selection
DFT	-	Discrete Fourier Transform
DMS	-	Discrete Memoryless Source
DMT	-	Discrete Multi-Tone Modulation
DS	-	Downstream
DSA	-	Dynamic Spectrum Access
DSL	-	Digital Subscriber Line
DSP	-	Digital Signal Processing
DTV	-	Digital Television
DVB-T	-	Digital Video Broadcasting - Terrestrial
ED	-	Energy Detector
EIRP	-	Effective Isotropic Radiated Power
EME	-	Energy with Minimum Eigenvalue
ETSI	-	European Telecommunication Standard Institute

EVD	-	Eigenvalue Decomposition
EVDSD	-	Eigenvalue Decomposition Signal Detector
FCC	-	Federal Communication Commission
FDM	-	Frequency-Division Multiplexing
FFT	-	Fast Fourier Transform
FP	-	False positive
FPGA	-	Field-Programmable Gate Array
GLRT	-	Generalized Likelihood Ratio Test
GPS	-	Global Positioning System
i.i.d.	-	Independent and Identically Distributed
IDFT	-	Inverse Discrete Fourier Transform
IEEE	-	International Electrical and Electronics Engineer
IF	-	Intermediate Frequency
IFFT	-	Inverse Fast Fourier Transform
IMT	-	International Mobile Telecommunications
ISI	-	Intersymbol Interference
ISM	-	Industrial, Scientific, and Medical
ITU	-	International Telecommunication Union
ITU-R	-	ITU Radiocommunication Sector
LAN	-	Local Area Network
LAN/MAN	-	Local Area Network/Metropolitan Area Network
LU	-	Lower and Upper
MAN	-	Metropolitan Area Network
MCMC	-	Malaysian Communication and Multimedia Commission
MF	-	Matched Filter
MIMO	-	Multiple Input Multiple Output
ML	-	Maximum Likelihood
MME	-	Maximum-Minimum Eigenvalue
NPRM	-	Notice of Proposed Rulemaking
OFDM	-	Orthogonal Frequency-Division Multiplexing
PAN	-	Personal Area Network
P_d	-	Probability of Detection
PDA	-	Personal Digital Assistant
PDF	-	Probability Density Function
P_{fa}	-	Probability of False Alarm
P_{md}	-	Probability of Miss Detection

PSD	-	Power Spectral Density
PU	-	Primary User
QAM	-	Quadrature Amplitude Modulation
QPSK	-	Quadrature Phase Shift Keying
RAN	-	Regional Area Network
RF	-	Radio Frequency
RMT	-	Random Matrix Theory
ROC	-	Receiver Operating Characteristic
RTSA	-	Real Time Spectrum Analyzer
SDR	-	Software-Defined Radio
SDT	-	Signal Detection Theory
SG	-	Study Group
SNR	-	Signal-to-Noise Ratio
SU	-	Secondary User
SVD	-	Singular Value Decomposition
SVDSD	-	Singular Value Decomposition Signal Detector
TP	-	True Positive
TV	-	Television
UHF	-	Ultra High Frequency
UMTS	-	Universal Mobile Telecommunications System
US	-	Upstream
UWB	-	Ultra-Wideband
VHF	-	Very High Frequency
WAN	-	Wide Area Network
WG	-	Working Group
WiMAX	-	Worldwide Interoperability for Microwave Access
WP	-	Working Parties
WRAN	-	Wireless Regional Area Network
WRC	-	World Radiocommunication Conference

CHAPTER ONE

INTRODUCTION

This thesis is about an innovative signal detection algorithm and its performance for IEEE 802.22 Wireless Regional Area Network (WRAN) to detect licensed user signal in order to avoid harmful interference to the incumbent. The aim of this chapter is to place the thesis in its context, where general overview of the research is described briefly. This chapter begins with highlighting the current spectrum usage in the next section. Section 1.2 highlights the motivation of the research and the worldwide organizational effort to utilize spectrum resources. The problem statement is described in Section 1.3 where the current situation of spectrum resource management is being addressed. In Section 1.4, the research questions are being addressed. The objectives, scope, and steps of the research are described briefly in Section 1.5, 1.6, and 1.7 respectively. The contributions of the research are highlighted in Section 1.8, and finally, the organization of the thesis is outlined in Section 1.9.

1.1 Current Spectrum Usage

In recent years there has been a major increase of wireless applications that have been deployed, and along with more traditional services, this has placed a significant amount of pressure on sharing the available spectrum, especially in Very High Frequency (VHF) and Ultra High Frequency (UHF) bands. This is because these bands are considered as a "sweet spot" for their advantages in propagating signals and low hardware cost.

Furthermore, the radio frequency spectrum is a limited natural resource to enable wireless communication between transmitters and receivers [21]. The radio spectrum

REFERENCES

[1] H. Abdi, "Signal detection theory," in *International Encyclopedia of Education*, 3rd ed., P. Peterson, E. Baker, and B. McGaw, Eds. New York: Elsevier, 2010, vol. 7, pp. 407 – 410.

[2] A. Buccardo, "A signal detector for cognitive radio system," Master Thesis, Department of Technology and Built Environment, University of Gavle, Sweden, Jun. 2010.

[3] R. Jain, *Art of Computer Systems Performance Analysis: Techniques for Experimental Design Measurements Simulation and Modeling*. John Wiley & Sons, Inc., 1991.

[4] Radio-Electronics.com, "What is DVB-T?" [Online]. Available: http://www.radio-electronics.com/info/broadcast/digital-video-broadcasting/what-is-dvb-t-basics-tutorial.php

[5] *Digital broadcasting systems for television, sound and data services; framing structure, channel coding, and modulation for digital terrestrial television*, European Broadcasting Union Std., Rev. V1.5.1, 2004. [Online]. Available: http://www.etsi.org

[6] S. H. Hwang, J. S. Um, M. S. Song, C. J. Kim, H. R. Park, and Y. H. Kim, "Design and verification of IEEE 802.22 WRAN physical layer," in *Third International Conference on Cognitive Radio Oriented Wireless Networks and Communications, 2008 (CrownCom 2008)*, May 2008, pp. 1 – 6.

[7] I. Mitola, J., *Cognitive Radio Architecture: The Engineering Foundations of Radio XML*. Wiley, Sep. 2006.

[8] J. Mitola, "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio," PhD Thesis, Royal Institute of Technology (KTH), Stockholm, Sweden, Teleinformatics, Electrum 204, SE-164 40 Kista, Sweden, May 2000.

[9] Q. Zhao and A. Swami, "A survey of dynamic spectrum access: Signal processing and networking perspectives," in *Acoustics, Speech and Signal Processing, 2007. ICASSP 2007. IEEE International Conference on*, vol. 4, april 2007, pp. IV–1349 –IV–1352.

[10] J. Lundén, "Spectrum sensing for cognitive radio and radar systems," Ph.D. dissertation, Department of Signal Processing and Acoustics, Faculty of Electronics, Communications and Automation, Helsinki University of Technology, Nov. 2009.

[11] K.-C. Chen and R. Prasad, *Cognitive Radio Networks*. West Sussex, United Kingdom: John Wiley & Sons, 2009.

[12] W. H. Tranter, K. S. Shanmugan, T. S. Rappaport, and K. L. Kosbar, *Principles of Communication Systems Simulation with Wireless Applications*. Upper Saddle River, NJ 07458: Prentice Hall, 2004, iSBN: 0-13-494790-8.

[13] S. Hassan, "Simulation-based performance evaluation of TCP-friendly protocols for supporting multimedia application in the internet," PhD Thesis, Computer Science Department, University of Leeds, 2002.

[14] O. Ghazali, "Scaleable and smooth TCP-friendly receiver-based layered multicast protocol," PhD Thesis, College of Arts and Sciences, Universiti Utara Malaysia, 2008.

[15] O. B. Lynn, "A hybrid mechanism for SIP over IPv6 macromobility and micromobility management protocols," PhD Thesis, College of Arts and Sciences, Universiti Utara Malaysia, 2008.

[16] R. G. Sargent, "Validation and verification of simulation models," in *Winter Simulation Conference*, 2004, pp. 39 – 48.

[17] T. Fawcett, "An introduction to ROC analysis," *Pattern Recognition Letters*, vol. 27, pp. 861 – 874, Jun. 2006. [Online]. Available: http://portal.acm.org/citation.cfm?id=1159473.1159475

[18] ——, "Using rule sets to maximize ROC performance," in *Proceedings IEEE International Conference on Data Mining, 2001 (ICDM 2001)*, 2001, pp. 131 – 138.

[19] Y. Zeng and Y.-C. Liang, "Eigenvalue-based spectrum sensing algorithms for cognitive radio," *IEEE Transactions on Communications*, vol. 57, no. 6, pp. 1784 – 1793, Jun. 2009.

[20] IEEE 802.22 Working Group of the LAN/MAN Standards Committee, "IEEE P802.22 DRAFTv3.0 Draft Standard for Wireless Regional Area Networks Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands," Apr. 2010.

[21] M. Matinmikko, M. Mustonen, H. Sarvanko, M. Hoyhtya, A. Hekkala, A. Mammela, M. Katz, and M. Kiviranta, "A motivating overview of cognitive radio: Foundations, regulatory issues and key concepts," in *First International Workshop on Cognitive Radio and Advanced Spectrum Management, 2008 (CogART 2008).*, Feb. 2008, pp. 1–5.

[22] Report ITU-R M. 2072, "World mobile telecommunication market forecast," International Telecommunication Union Radiocommunication (ITU-R), Tech. Rep., 2006.

[23] SKMM, *Spectrum Plan*. Malaysian Communications and Multimedia Commission (SKMM), Nov. 2006.

[24] G. Staple and K. Werbach, "The end of spectrum scarcity," *IEEE Spectrum*, vol. 41, no. 3, pp. 48 – 52, Mar. 2004.

[25] FCC Spectrum Policy Task Force, "Report of the spectrum efficiency working group," Federal Communication Commission (FCC), Tech. Rep., 2002.

[26] M. A. McHenry, "Spectrum occupancy measurements," 2005. [Online]. Available: http://www.sharedspectrum.com/measurements/

[27] M. H. Omar, S. Hassan, and A. H. Mohd-Shabli, "Feasibility study of using IEEE 802.22 Wireless Regional Area Network (WRAN) in Malaysia," in *Second International Conference on Network Applications, Protocols and Services (NETAPPS) 2010*, Sep. 2010, pp. 198 – 202.

[28] M. H. Omar, S. Hassan, and M. M. Kadhum, "Connecting the last mile using the IEEE 802.22 Wireless Regional Area Network (WRAN) in Malaysia," in *Proceeding of the Fifth Social Economic and Information Technology (SEiT) Conference*, Haadyai, Thailand, Nov. 2010, pp. 274 – 282.

[29] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE Journal on Selected Areas in Communications*, vol. 23, no. 2, pp. 201 – 220, Feb. 2005.

[30] F. H. P. Fitzek and M. D. Katz, *Cognitive Wireless Networks - Concepts, Methodologies and Visions Inspiring the Age of Enlightenment of Wireless Communications*. Springer, 2007.

[31] ITU-R, "Final Acts WRC-07 - World Radiocommunication Conference (Geneva, 2007)," International Telecommunication Union (ITU), Geneva, Tech. Rep., 2008.

[32] W. Hu, M. Gerla, G. Vlantis, and G. Pottie, "Efficient, flexible, and scalable inter-network spectrum sharing and communications in cognitive IEEE 802.22 networks," in *First International Workshop on Cognitive Radio and Advanced Spectrum Management, 2008 CogART 2008*, feb. 2008, pp. 1 –5.

[33] J. Mitola and G. Q. Maguire, "Cognitive radio: Making software radios more personal," *Personal Communications, IEEE*, vol. 6, no. 4, pp. 13 – 18, Aug. 1999.

[34] S. Xu, Y. Shang, and H. Wang, "Application of SVD to sense wireless microphone signals in a wideband cognitive radio network," in *Second International Conference on Signal Processing and Communication Systems, 2008 (ICSPCS 2008)*, Dec. 2008, pp. 1 – 7.

[35] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," *IEEE Communications Surveys & Tutorials*, vol. 11, no. 1, pp. 116 – 130, Mar. 2009.

[36] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer Networks*, vol. 50, no. 13, pp. 2127 – 2159, 2006.

[37] ——, "A survey on spectrum management in cognitive radio networks [cognitive radio communications and networks]," *IEEE Communications Magazine*, vol. 46, no. 4, pp. 40 – 48, Apr. 2008.

[38] Y. Zeng, Y.-C. Liang, A. T. Hoang, and R. Zhang, "A review on spectrum sensing for cognitive radio: Challenges and solution," *EURASIP Journal on Advances in Signal Processing*, vol. 2010, 2010, article ID 381465. [Online]. Available: http://downloads.hindawi.com/journals/asp/2010/381465.pdf

[39] A. Kortun, T. Ratnarajah, M. Sellathurai, and C. Zhong, "On the performance of eigenvalue-based spectrum sensing for cognitive radio," in *IEEE Symposium on New Frontiers in Dynamic Spectrum, 2010*, Apr. 2010, pp. 1 – 6.

[40] Y. Zeng and Y.-C. Liang, "Maximum-minimum eigenvalue detection for cognitive radio," in *IEEE Eighteenth International Symposium on Personal, Indoor and Mobile Radio Communications PIMRC 2007.*, Sep. 2007, pp. 1 – 5.

[41] L. Cardoso, M. Debbah, P. Bianchi, and J. Najim, "Cooperative spectrum sensing using random matrix theory," May 2008, pp. 334 – 338.

[42] M. H. Omar, S. Hassan, and A. H. Mohd-Shabli, "COGRADNET: Ubiquitous heterogeneous wireless networks," *Journal of Engineering Science and Technology*, vol. 2, no. 2, pp. 184 – 195, Jun. 2009.

[43] M. H. Omar, A. H. Mohd-Shabli, and S. Hassan, "CogRadNet: Ubiquitous heterogeneous wireless networks," in *Proceedings of International Conference on Network Applications, Protocols and Services 2008 (NetApps2008)*. UUM College of Arts and Sciences, Universiti Utara Malaysia, Nov. 2008, ISBN: 9789832078333.

[44] M. Buddhikot, "Understanding dynamic spectrum access: Models, taxonomy and challenges," in *Second IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2007 (DySPAN 2007)*, Apr. 2007, pp. 649 – 663.

[45] Anonymous, "What is software defined radio?" April 2011, accessed on 15 April 2011. [Online]. Available: http://www.wirelessinnovation.org/assets/documents/SoftwareDefinedRadio.pdf

[46] Q. Zhao and B. Sadler, "A survey of dynamic spectrum access," *IEEE Signal Processing Magazine*, vol. 24, no. 3, pp. 79 – 89, May 2007.

[47] W. Lehr and J. Crowcroft, "Managing shared access to a spectrum commons," in *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005 (DySPAN 2005)*, Nov. 2005, pp. 420 – 444.

[48] D. Cabric, S. Mishra, and R. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in *Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems and Computers*, vol. 1, Nov. 2004, pp. 772 – 776.

[49] A. Ghasemi and E. Sousa, "Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs," *IEEE Communications Magazine*, vol. 46, no. 4, pp. 32 – 39, Apr. 2008.

[50] T. C. Clancy, "Formalizing the interference temperature model," *Wireless Communications and Mobile Computing*, vol. 7, no. 9, pp. 1077 – 1086, Nov. 2007.

[51] S. Haykin, *Fundamental Issues in Cognitive Radio*, E. Hossain and V. K. Bhargava, Eds. Springer, 2007.

[52] Q. Zhao, "Spectrum opportunity and interference constraint in opportunistic spectrum access," in *IEEE International Conference on Acoustics, Speech and Signal Processing, 2007 (ICASSP 2007)*, vol. 3, Apr. 2007, pp. III–605 – III–608.

[53] Q. Zhao, W. Ren, and A. Swami, "Spectrum opportunity detection: How good is listen-before-talk?" in *Proceedings of the Forty-First Asilomar Conference on Signals, Systems and Computers*, Nov. 2007, pp. 767 – 771.

[54] T. Brown, "An analysis of unlicensed device operation in licensed broadcast service bands," in *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005 (DySPAN 2005)*, Nov. 2005, pp. 11 – 29.

[55] J. I. Marcum, "A statistical theory of target detection by pulsed radar," RAND Corporation, Working Paper, Dec. 1947. [Online]. Available: http://www.rand.org/content/dam/rand/pubs/research_memoranda/2006/RM754.pdf

[56] D. Cabric, A. Tkachenko, and R. W. Brodersen, "Spectrum sensing measurements of pilot, energy, and collaborative detection," in *Proceedings of the Military Communications Conference (MILCOM)*, Oct. 2006, pp. 1 – 7.

[57] D. Cabric, "Addressing feasibility of cognitive radios," *IEEE Signal Processing Magazine*, vol. 25, no. 6, pp. 85 – 93, Nov. 2008.

[58] S. V. Nagaraj, "Entropy-based spectrum sensing in cognitive radio," *Signal Processing*, vol. 89, no. 6, pp. 174 – 180, Feb. 2009.

[59] W. A. Gardner, A. Napolitano, and L. Paura, "Cyclostationarity: Half a century of research," *Signal Processing*, vol. 86, no. 4, pp. 639 – 697, Apr. 2006.

[60] W. Gardner, "Spectral correlation of modulated signals: Part I–Analog modulation," *IEEE Transactions on Communications*, vol. 35, no. 6, pp. 584 – 594, Jun. 1987.

[61] W. Gardner, W. Brown, and C.-K. Chen, "Spectral correlation of modulated signals: Part II–Digital modulation," *IEEE Transactions on Communications*, vol. 35, no. 6, pp. 595 – 601, Jun. 1987.

[62] A. Napolitano and C. Spooner, "Cyclic spectral analysis of continuous-phase modulated signals," *IEEE Transactions on Signal Processing*, vol. 49, no. 1, pp. 30 – 44, Jan. 2001.

[63] H. Bolcskei, "Blind estimation of symbol timing and carrier frequency offset in wireless OFDM systems," *IEEE Transactions on Communications*, vol. 49, no. 6, pp. 988 – 999, Jun. 2001.

[64] M. Oner and F. Jondral, "On the extraction of the channel allocation information in spectrum pooling systems," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 3, pp. 558 – 565, Apr. 2007.

[65] A. Tkachenko, A. Cabric, and R. Brodersen, "Cyclostationary feature detector experiments using reconfigurable BEE2," in *Second IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2007 DySPAN 2007*, Apr. 2007, pp. 216 – 219.

[66] W. Gardner, "Signal interception: A unifying theoretical framework for feature detection," *IEEE Transactions on Communications*, vol. 36, no. 8, pp. 897 – 906, Aug. 1988.

[67] W. Gardner and C. Spooner, "Signal interception: Performance advantages of cyclic-feature detectors," *IEEE Transactions on Communications*, vol. 40, no. 1, pp. 149 – 159, Jan. 1992.

[68] ——, "Detection and source location of weak cyclostationary signals: Simplifications of the maximum-likelihood receiver," *IEEE Transactions on Communications*, vol. 41, no. 6, pp. 905 – 916, Jun. 1993.

[69] L. Izzo, L. Paura, and M. Tanda, "Signal interception in non-Gaussian noise," *IEEE Transactions on Communications*, vol. 40, no. 6, pp. 1030 – 1037, Jun. 1992.

[70] P. Rostaing, E. Thierry, and T. Pitarque, "Asymptotic performance analysis of the single-cycle detector," in *Proceedings of the European Signal Processing Conference (EUSIPCO)*, Sep. 1996.

[71] E. Serpedin, F. Panduru, I. Sari, and G. B. Giannakis, "Bibliography on cyclostationarity," *Signal Processing*, vol. 85, no. 12, pp. 2233 – 2303, Dec. 2005.

[72] S. M. Kay, *Fundamentals of Statistical Signal Processing: Volume 2, Detection Theory*. Upper Saddle River, NJ: Prentice-Hall, 1998.

[73] G. B. Giannakis, Y. Hua, P. Stoica, and L. Tong, *Signal Processing Advances in Wireless and Mobile Communications: Trends in Channel Estimation and Equalization*. Prentice Hall PTR, 2000, vol. 1.

[74] H. L. Van-Trees, *Detection, Estimation and Modulation Theory*. New York, NY, USA: John Wiley & Sons, 2001.

[75] T. J. Lim, R. Zhang, Y. C. Liang, and Y. Zeng, "GLRT-based spectrum sensing for cognitive radio," in *IEEE Global Telecommunications Conference, 2008 (IEEE GLOBECOM 2008)*, Dec. 2008, pp. 1 – 5.

[76] Z. Tian and G. B. Giannakis, "A wavelet approach to wideband spectrum sensing for cognitive radios," in *First International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, Jun. 2006, pp. 1 – 5.

[77] Z. Tian and G. Giannakis, "Compressed sensing for wideband cognitive radios," in *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP 2007)*, vol. 4, 2007, pp. IV–1357 –IV–1360.

[78] Y. Polo, Y. Wang, A. Pandharipande, and G. Leus, "Compressive wide-band spectrum sensing," pp. 2337 – 2340, Apr. 2009.

[79] Y. Wang, A. Pandharipande, Y. Polo, and G. Leus, "Distributed compressive wide-band spectrum sensing," in *Information Theory and Applications Workshop*, t, Ed., Feb. 2009, pp. 178 – 183.

[80] Y. Hur, J. Park, W. Woo, K. Lim, C.-H. Lee, H. Kim, and J. Laskar, "A wideband analog multi-resolution spectrum sensing (MRSS) technique for cognitive radio (CR) systems," in *Proceedings of IEEE International Symposium on Circuits and Systems, 2006 (ISCAS 2006)*, Sep. 2006, p. 4 pp.

[81] J. Park, Y. Hur, T. J. Song, K. Kim, J. Lee, K. Lim, C.-H. Lee, H. S. Kim, and J. Laskar, "Implementation issues of a wideband multi-resolution spectrum sensing (MRSS) technique for cognitlve radio (CR) systems," in *First International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, Jun. 2006, pp. 1 –5.

[82] Y. Youn, H. Jeon, H. Jung, and H. Lee, "Discrete wavelet packet transform based energy detector for cognitive radios," in *IEEE Sixty-Fifth Vehicular Technology Conference (VTC2007-Spring)*, Apr. 2007, pp. 2641 – 2645.

[83] H. Urkowitz, "Energy detection of a random process in colored Gaussian noise," *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-5, no. 2, pp. 156 – 162, Mar. 1969.

[84] J. Moragues, L. Vergara, J. Gosalbez, and I. Bosch, "An extended energy detector for non-Gaussian and non-independent noise," *Signal Processing*, vol. 89, no. 4, pp. 656 – 661, Apr. 2009.

[85] A. Sonnenschein and P. Fishman, "Radiometric detection of spread-spectrum signals in noise of uncertain power," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 28, no. 3, pp. 654 – 660, Jul. 1992.

[86] R. Tandra and A. Sahai, "SNR walls for signal detection," *IEEE Journal of Selected Topics in Signal Processing*, vol. 2, no. 1, pp. 4 – 17, Feb. 2008.

[87] D. J. Torrieri, *Principles of Military Communication Systems*. Dedham, MA: Artech, 1981.

[88] J. Lehtomaki, "Analysis of energy based signal detection," Ph.D. dissertation, Faculty of Technology, University of Oulu, 2005. [Online]. Available: http://herkules.oulu.fi/isbn9514279255/.

[89] A. Ghasemi and E. S. Sousa, "Opportunistic spectrum access in fading channels through collaborative sensing," *Journal of Communications*, vol. 2, no. 2, pp. 71 – 82, Mar. 2007.

[90] J. Ma and Y. Li, "Soft combination and detection for cooperative spectrum sensing in cognitive radio networks," in *IEEE Global Telecommunications Conference, 2007 (GLOBECOM '07)*, Nov. 2007, pp. 3139 – 3143.

[91] H. Kim and K. G. Shin, "In-band spectrum sensing in cognitive radio networks: Energy detection or feature detection?" in *Proceedings of the Fourteenth ACM International Conference on Mobile Computing and Networking (MobiCom)*, Sep. 2008, pp. 14 – 25.

[92] J. Lehtomaki, M. Juntti, and H. Saarnisaari, "CFAR strategies for channelized radiometer," *IEEE Signal Processing Letters*, vol. 12, no. 1, pp. 13 – 16, Jan. 2005.

[93] V. Kostylev, "Energy detection of a signal with random amplitude," in *IEEE International Conference on Communications, 2002 (ICC 2002)*, vol. 3, 2002, pp. 1606 – 1610.

[94] F. Digham, M.-S. Alouini, and M. Simon, "On the energy detection of unknown signals over fading channels," vol. 5, pp. 3575 – 3579, May 2003.

[95] A. Ghasemi and E. Sousa, "Collaborative spectrum sensing for opportunistic access in fading environments," in *First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005 (DySPAN 2005)*, Nov. 2005, pp. 131 – 136.

[96] ——, "Impact of user collaboration on the performance of sensing-based opportunistic spectrum access," in *2006 IEEE Sixty-Fourth Vehicular Technology Conference, 2006 (VTC-2006-Fall)*, Sep. 2006, pp. 1 – 6.

[97] S. Mishra, R. Brodersen, S. Brink, and R. Mahadevappa, "Detect and avoid: An ultra-wideband/WiMAX coexistence mechanism [topics in radio communications]," *IEEE Communications Magazine*, vol. 45, no. 6, pp. 68 – 75, Jun. 2007.

[98] H.-S. Chen, W. Gao, and D. Daut, "Spectrum sensing for wireless microphone signals," in *Fifth IEEE Annual Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks Workshops, 2008 (SECON Workshops '08).*, Jun. 2008, pp. 1 – 5.

[99] S. A. Kassam, *Signal Detection in Non-Gaussian Noise*. New York: Springer-Verlag, 1988.

[100] Y. Zeng and Y.-C. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 4, pp. 1804 – 1815, May 2009.

[101] Y. Zeng, Y. C. Liang, and R. Zhang, "Blindly combined energy detection for spectrum sensing in cognitive radio," *IEEE Signal Processing Letters*, vol. 15, pp. 649 – 652, 2008.

[102] S. Xu, Y. Shang, and H. Wang, "SVD based sensing of a wireless microphone signal in cognitive radio networks," in *Eleventh IEEE Singapore International Conference on Communication Systems, 2008 (ICCS 2008)*, Nov. 2008, pp. 222 – 226.

[103] ——, "Eigenvalues based spectrum sensing against untrusted users in cognitive radio networks," in *Cognitive Radio Oriented Wireless Networks and Communications, 2009. CROWNCOM '09. 4th International Conference on*, june 2009, pp. 1 –6.

[104] F. Penna, R. Garello, D. Figlioli, and M. Spirito, "Exact non-asymptotic threshold for eigenvalue-based spectrum sensing," Jun. 2009, pp. 1 – 5.

[105] E. Axell and E. Larsson, "Spectrum sensing of orthogonal space-time block coded signals with multiple receive antennas," in *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, march 2010, pp. 3110 –3113.

[106] L. De Vito, D. Napolitano, S. Rapuano, and M. Villanacci, "Eigenvalue-based signal detector for an automatic modulation classifier," in *Instrumentation and Measurement Technology Conference (I2MTC), 2010 IEEE*, may 2010, pp. 1131 –1136.

[107] R. Wang and M. Tao, "Blind spectrum sensing by information theoretic criteria for cognitive radios," *Vehicular Technology, IEEE Transactions on*, vol. 59, no. 8, pp. 3806 –3817, oct. 2010.

[108] Y.-C. Liang, G. Pan, and Y. Zeng, "On the performance of spectrum sensing algorithms using multiple antennas," in *GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference*, dec. 2010, pp. 1 –5.

[109] A. Adelman and N. R. Rao, "Random matrix theory," Massachusetts Institute of Technology, Cambridge, MA 02139, USA, Tech. Rep., 2005. [Online]. Available: http://web.mit.edu/18.338/www/Acta05rmt.pdf

[110] S. Leach, "Singular value decomposition - a primer." [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.2.6587

[111] A. Sahai and D. Cabric, "Spectrum sensing: Fundamental limits and practical challenges," in *IEEE International Symposium on New Frontiers Dynamic Spectrum Access Networks (DySPAN)*, Nov. 2005, Baltimore, MD.

[112] H.-S. Chen, W. Gao, and D. Daut, "Signature based spectrum sensing algorithms for IEEE 802.22 WRAN," in *IEEE International Conference on Communications, 2007 (ICC '07)*, Jun. 2007, pp. 6487 – 6492.

[113] C. E. Shannon, "Communication in the presence of noise," in *Proceedings of the IEEE*, vol. 86, no. 2, Feb. 1998.

[114] L. Tong, G. Xu, and T. Kailath, "Blind identification and equalization based on second-order statistics: A time domain approach," *IEEE Transactions on Information Theory*, vol. 40, no. 2, pp. 340 – 349, Mar. 1994.

[115] E. Moulines, P. Duhamel, J. Cardoso, and S. Mayrargue, "Subspace methods for the blind identification of multichannel FIR filters," in *IEEE International Conference on Acoustics, Speech, and Signal Processing, 1994 (ICASSP-94)*, vol. 4, Apr. 1994, pp. IV/573 – IV/576.

[116] J. G. Proakis and M. Salehi, *Digital Communications*, 5th ed. McGraw Hill, Jan. 2008.

[117] J.-Y. Le Boudec, *Performance Evaluation of Computer and Communication Systems*. EPFL Press, Lausanne, Switzerland, 2010.

[118] A. M. Law and W. D. Kelton, *Simulation Modelling and Analysis*, 3rd ed. McGraw-Hill, 2000.

[119] S. Bajaj, L. Breslau, D. Estrin, K. Fall, S. Floyd, P. Haldar, M. Handley, A. Helmy, J. Heidemann, P. Huang, S. Kumar, S. McCanne, R. Rejaie, P. Sharma, K. Varadhan, Y. Xu, H. Yu, and D. Zappala, "Improving simulation for network research," University of Southern California, Tech. Rep. 99-702b, Mar. 1999, revised September 1999, to appear in IEEE Computer. [Online]. Available: http://www.isi.edu/~johnh/PAPERS/Bajaj99a.html

[120] O. M. D. Al-Momani, "Dynamic redundancy forward error correction mechanism for the enhancement of internet-based video streaming," PhD Thesis, UUM College of Arts and Sciences, Universiti Utara Malaysia, 2010.

[121] A. P. Bradley, "The use of the area under the ROC curve in the evaluation of machine learning algorithms," *Pattern Recogn.*, vol. 30, pp. 1145 – 1159, Jul. 1997. [Online]. Available: http://dx.doi.org/10.1016/S0031-3203(96)00142-2

[122] J. A. Swets, R. M. Dawes, and J. Monahan, "Better decisions through science," *Scientific American*, vol. 283, no. 4, pp. 82 – 87, Oct. 2000. [Online]. Available: http://view.ncbi.nlm.nih.gov/pubmed/11011389

[123] F. Provost and T. Fawcett, "Robust classification for imprecise environments," *Machine Learning*, vol. 42, pp. 203 – 231, 2001, kluwer Academic Publishers.

[124] G. Acosta and M. A. Ingram, "OFDM simulation using Matlab," Aug. 2000, smart Antenna Research Laboratory, School of Electrical and Computer Engineering, Georgia Institute of Technology. [Online]. Available: http://www.ece.gatech.edu/research/labs/sarl/tutorials/OFDM/Tutorial_web.pdf

[125] V. Tawil, "51 captured DTV signal," May 2006. [Online]. Available: http://grouper.ieee.org/groups/802/22/

[126] I. M. Garrison, R. K. Martin, W. A. Sethares, B. Hart, W. Chung, J. Balakrishnan, R. A. Casas, T. J. Endres, M. Larimore, P. Schniter, and C. R. Johnson, "DTV channel characterization," in *Conference on Information Sciences and Systems*. The Johns Hopkins University, Mar. 2001. [Online]. Available: http://bard.ece.cornell.edu/downloads/data/dtv/dtv.html

[127] Broadband Adaptive Receiver Design, "DTV channel characterization." [Online]. Available: http://bard.ece.cornell.edu/downloads/data/dtv/dtv.html

[128] J. G. Proakis and D. K. Manolakis, *Digital Signal Processing: Principles, Algorithms and Applications*, 3rd ed. Prentice Hall, Oct. 1995.

[129] A. M. Tulino and S. Verdu, *Random Matrix Theory and Wireless Communications*. AD Delft, The Netherlands: Now Publishers Inc., 2004, iSBN: 1-933019-00-X.

[130] I. M. Johnstone, "On the distribution of the largest eigenvalue in principal components analysis," *Annals of Statistics*, vol. 29, no. 2, pp. 295 – 327, 2001.

[131] C. A. Tracy and H. Widom, *The distribution of the largest eigenvalue in the Gaussian ensembles*, ser. CRM Series in Mathematical Physics 4. New York: Springer-Verlag, 2000, pp. 641 – 472.

[132] C. Clanton, M. Kenkel, and Y. Tang, "Wireless microphone signal simulation method," Mar. 2007, iEEE 802.22-07/0124r0.

[133] S. Shellhammer, V. Tawil, G. Chouinard, M. Muterspaugh, and M. Ghosh, "Spectrum sensing simulation model," Feb. 2006. [Online]. Available: https://mentor.ieee.org/802.22/dcn/06/22-06-0028-06-0000-spectrum-sensing-simulation-model.doc

[134] R. Tandra and A. Sahai, "Fundamental limits on detection in low SNR under noise uncertainty," in *International Conference on Wireless Networks, Communications and Mobile Computing, 2005*, vol. 1, Jun. 2005, pp. 464 – 469.

[135] S. Shellhammer and R. Tandra, "Performance of the power detector with noise uncertainty," Jul. 2006, iEEE 802.22-06/0134r0.

[136] V. A. Labay and J. Bornemann, "Singular value decomposition improves accuracy and reliability of T-Spectrum waveguide field-matching analsis," *International Journal of Microwave and Milimeter-Wave Computer-Aided Engineering*, vol. 2, no. 2, pp. 82–89, 1992. [Online]. Available: http://www.ece.uvic.ca/~jbornema/Journals/036-92mmwcae-lb.pdf

[137] F. Penna, R. Garello, and M. Spirito, "Cooperative spectrum sensing based on the limiting eigenvalue ratio distribution in Wishart matrices," *IEEE Communications Letters*, vol. 13, no. 7, pp. 507 –509, Jul. 2009.

[138] D. Tufts and R. Kumaresan, "Singular value decomposition and improved frequency estimation using linear prediction," *IEEE Transactions on Acoustics, Speech and Signal Processing*, vol. 30, no. 4, pp. 671 – 675, Aug. 1982.

[139] P. Pawelczak, G. Janssen, and R. Prasad, "WLC10-4: Performance measures of dynamic spectrum access networks," in *IEEE Global Telecommunications Conference, 2006 (GLOBECOM '06)*, Dec. 2006, pp. 1 – 6.

[140] R. V. Nee and R. Prasad, *OFDM Wireless Multimedia Communications*. Norwood, MA: Artech House Publishers, 2000.

[141] M. H. Omar, "Will cognitive radio take over spectrum management?" *.my Convergence Magazine*, vol. 3, no. 1, pp. 29 – 33, Jan. 2009. [Online]. Available: http://myconvergence.com.my/main/images/stories/PDF_Folder/jan2009/MYC04_all_lowres.pdf

[142] G. Feng, W. Chen, and Z. Cao, "A joint PHY-MAC spectrum sensing algorithm exploiting sequential detection," *IEEE Signal Processing Letters*, vol. 17, no. 8, pp. 703 – 706, Aug. 2010.

[143] H. Jiang, L. Lai, R. Fan, and H. Poor, "Optimal selection of channel sensing order in cognitive radio," *Wireless Communications, IEEE Transactions on*, vol. 8, no. 1, pp. 297 – 307, Jan. 2009.

[144] K. Johansson, "Shape fluctuations and random matrices," *Communications in Mathematical Physics*, vol. 209, pp. 437 – 476, 2000, 10.1007/s002200050027. [Online]. Available: http://www.citebase.org/abstract?id=oai:arXiv.org:math/9903134