Spectrum Sensing Technologies for Cognitive Radio Based Interactive Broadcasting Services

□ Kyutae Lim*, Youngsik Hur**, Jeong-Suk Lee***, Kihong Kim***, Chang-Ho Lee**, Haksun Kim**** and Joy Laskar*
/ *Georgia Electronic Design Center (GEDC), Georgia Institute of Tech., **Samsung RFIC Design Center at Georgia Tech., ***Samsung Electro-Mechanics Inc., ****Hanbat National Univ.

ABSTRACT

The Cognitive Radio (CR) technology is a promising solution for exploiting the limited spectrum resources and providing flexibility of spectrum usage. Future interactive broadcasting service can be realized by utilizing CR concept, since the up-link return channel can be found by the spectrum sensing method, which is core functional block of the CR system. In this paper, the spectrum sensing technologies of CR system is presented. First the system architecture of the CR with spectrum sensing block is presented. The suggested spectrum sensing technique consists of the coarse and the fine spectrum sensing. The coarse spectrum sensing technique adopted the wavelet transform to provide the multi-resolution sensing feature – Multi-Resolution Spectrum Sensing (MRSS). The fine spectrum sensing technique uses the beneficial properties of the autocorrelation function – Analog Auto-Correlation (AAC). The simulation results for the proposed sensing technologies are presented for various incumbent signals.

I. INTRODUCTION

The popularization of the internet and mobile communication, along with the development of high-speed wired network technology, created a new era of a fusion between broadcasting and communication. A new type of a user market is expected to emerge with the development of this broadcast-communication fusion, interactive broadcasting being the main example. The acquisition of return channels is a technological issue for surpassing conventional one-directional broadcasting services and implementing interactive broadcasting services in their place.

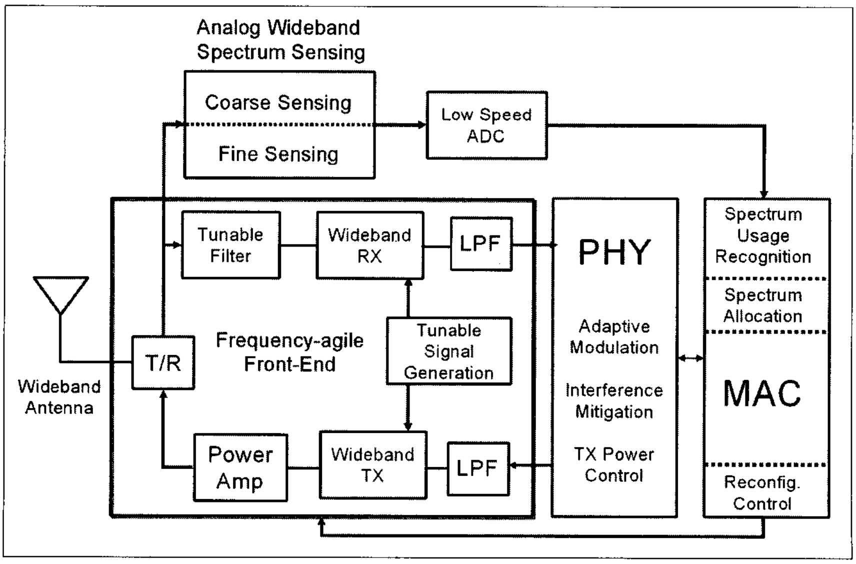
In the recent past, the Cognitive Radio (CR) technology has been considered as an attractive solution for exploiting the limited spectrum resources. The CR system is supposed to implement negotiated or opportunistic spectrum sharing over a wide frequency range covering multiple mobile communication standards [1]. Cognitive radio technology locates available channels surrounding a user, and as it allows for communication through these channels, a standardization project is already in the works at IEEE 802.22 to commercialize the technology for communicative use [2].

Not only for data communication, CR concept can be considered as a enabling technology for a interactive broadcasting service. The up-link channel, that would be used for a viewer to send an information to the broadcaster, can be found without pre-specified channel assignment by CR technology. Spectrum-sensing, the core technology of cognitive radio, allows for the acquisition of open channels by quickly and accurately measuring broadband usage conditions surrounding the user. A viewer can convey specific information or communicate without being assigned a separate channel.

In this paper, we present CR architecture and the spectrum sensing technology. Chapter II, CR system with spectrum sensing block is explained. Chapter III and IV, two spectrum sensing technologies, Multi-Resolution Spectrum Sensing (MRSS) and Analog Auto-Correlation (AAC) methods are presented. The proposed sensing technologies are verified by system simulation. The simulation results for various signals are presented.

II. THE CR SYSTEM ARCHITECTURE

This paper suggests the CR system architecture



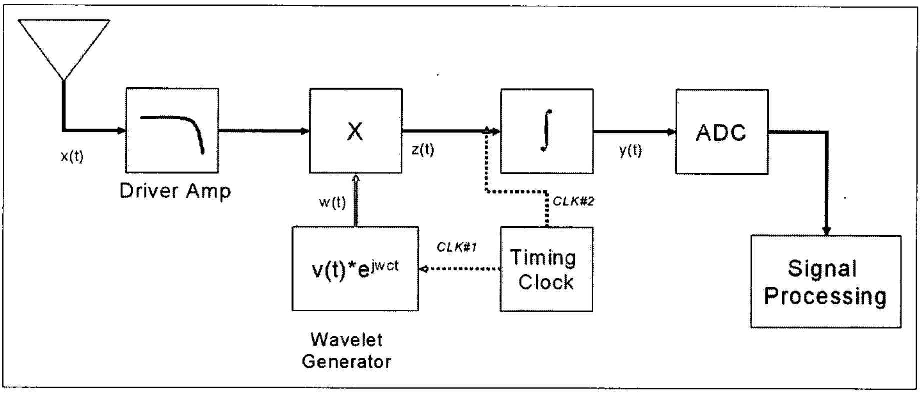
〈Fig. 1〉 The suggested Cognitive Radio system architecture shown in Fig. 1. The CR system comprised of (i) a wideband antenna, (ii) the frequency-agile front-end having wideband and reconfigurable features, (iii) the analog wideband spectrum sensing block with dual stages – the coarse- and the fine-sensing stages, (iv) the physical layer signal processing block (PHY) and (v) the medium access control block (MAC).

Unique part of the system is the spectrum sensing block that detects the unoccupied spectrum resources and determines the RF frequency for the CR link. In order to find the unoccupied spectrum segments, the spectrum sensing block explores the wide range of spectrum resources. This work suggests the spectrum sensing technique consisted of dual sensing stages – the coarse and the fine spectrum sensing [3]. These two sensing stages collaborate with each other to enhance the accuracy of the spectrum detection performance. The coarse spectrum sensing technique adopted the wavelet transform to provide the multi-resolution sensing feature – Multi-Resolution Spectrum Sensing (MRSS). This feature realizes the flexible detecting resolution without any hardware burden increase. Meanwhile, the fine spectrum sensing exploits the periodic feature of the input signals unique for each modulation format or frame structure. This fine sensing technique uses the beneficial properties of the autocorrelation function – Analog Auto-Correlation (AAC). This fine sensing technique identifies the signal type and provides this information to PHY for the mitigation of interference effects. The resulting spectrum usage status is reported to the MAC. This MAC processes the reported data to allocate the available spectrum for safe CR link. Additionally, the MAC provides the reconfiguration control signal to the radio front-end (RFE) for the optimal radio link in the allocated frequencies. Then, this frequency-agile RFE changes the operating RF frequency to the corresponding frequency value.

III. MULTI-RESOLUTION SPECTRUM SENSING

The Fourier transform derives the spectral representation of the given time domain signal. Meanwhile, the wavelet transform has various choices of the basis functions [4]. Certain types of the wavelet basis functions may have the bandwidth, the carrier frequency and period as the freedom of design. The wavelet transform coefficient is the correlation of the given signal with the specific wavelet basis waveform. Therefore, by adjusting the wavelet pulse width and the carrier frequency, the spectral contents for the given signal can be represented with the scalable resolution or multi-resolution. Moreover, wavelet transform is able to analyze the spectral contents of the time-variant signals by changing these pulse width and frequency after maintaining them within certain interval.

The MRSS is suggested as the coarse spectrum



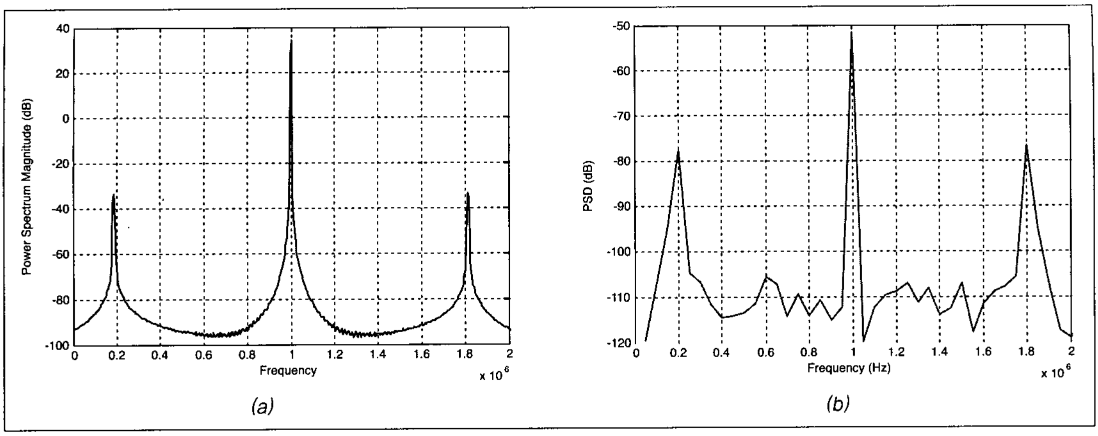
⟨Fig.2⟩ Functional block diagram of the suggested MRSS technique

sensing technique [5]. The wavelet transform is applied to the input signal and the resulting coefficient values stand for the representation of the input signal' s spectral contents with the given detection resolution. Fig. 2 shows the functional block diagram of the suggested MRSS technique. The building blocks consist of the analog wavelet waveform generator, the analog multiplier and the analog integrator for computing the correlation, and the low speed analog-to-digital signal converter (ADC) to digitize the calculated analog correlation values.

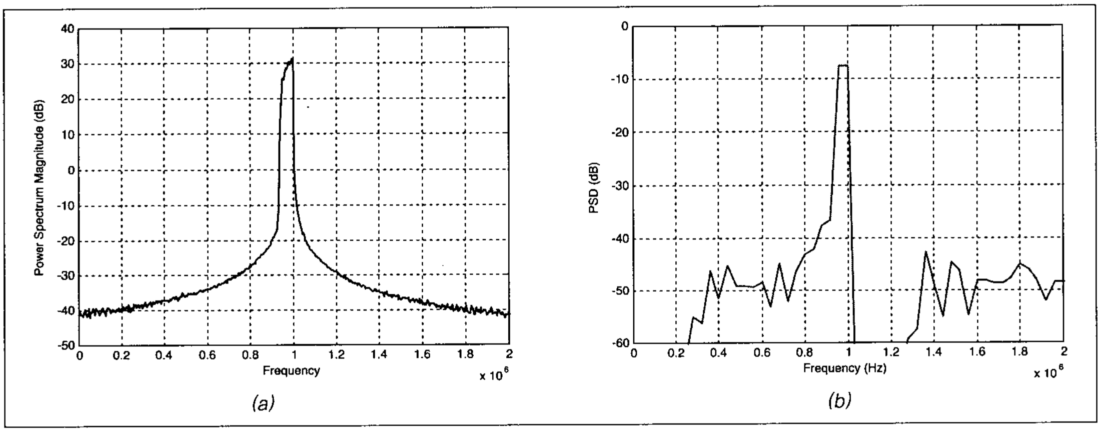
The wavelet pulse is generated and modulated with I-, Q-sinusoidal carrier with the given frequency. The correlations are calculated with the wavelet waveform with the given spectral width, i.e. the spectrum sensing resolution. By sweeping the local oscillator (LO) frequency with the certain interval, the signal power and the frequency values are detected over the spectrum range of interest. The resulting correlation with the I-, Q- components of the wavelet waveforms are digitized and their magnitudes are recorded. If these magnitudes are greater than the certain threshold level, the sensing scheme determines the meaningful interferer reception.

Since the analysis is performed in the analog domain, the high-speed operation and low-power consumption can be achieved [6]. By applying the narrow wavelet pulse and the large tuning step size of LO, this MRSS is able to examine the very wide spectrum span in the fast and sparse manner. On the contrary, very precise spectrum searching is realized with the wide wavelet pulse and the delicate adjusting LO frequency. By virtue of the scalable feature of the wavelet transform, multi-resolution is achieved without any additional digital hardware burdens. Moreover, unlike the heterodyne-based spectrum analysis techniques, this MRSS technique does not need any physical filters for image rejection due to the band pass filtering effect of the window signal.

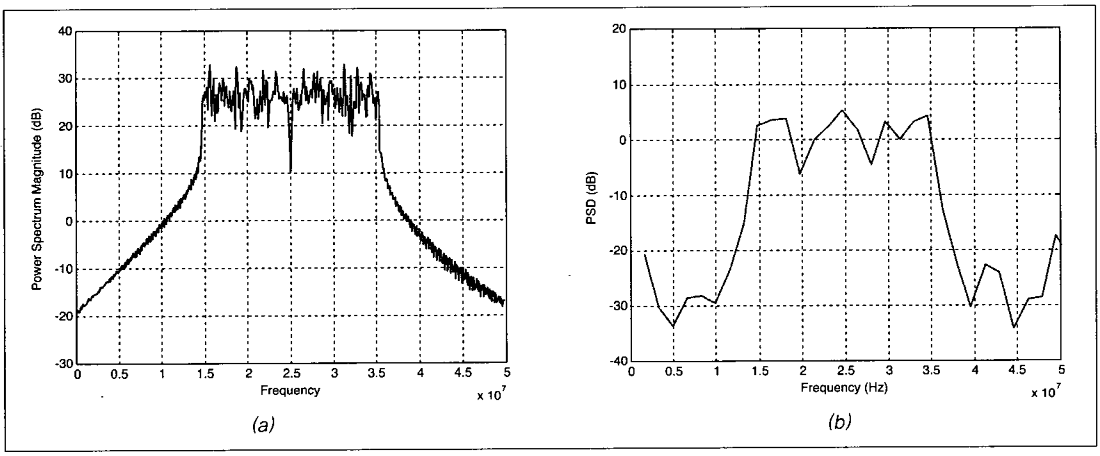
Fig. 3 - 5 show the simulation results of the



⟨Fig. 3⟩ The spectrum of (a) original FM signal and (b) the corresponding signal detected by MRSS



⟨Fig. 4⟩ The spectrum of (a) original ATSC signal and (b) the corresponding signal detected by MRSS



⟨Fig. 5⟩ The spectrum of (a) original OFDM signal and (b) the corresponding signal detected by MRSS suggested MRSS performance applied to the various signal formats, FM, ATDC, OFDM respectively. As shown in these figures, the MRSS technique achieved the universal detection performance for the targeted signal formats.

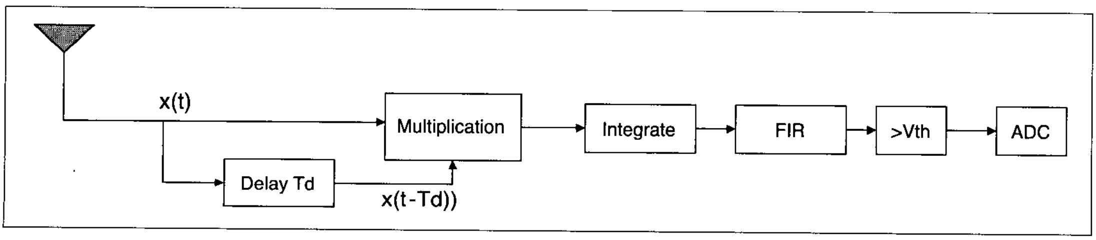
IV. ANALOG AUTO-CORRELATION

Most of the communication signals have the periodic features, i.e. sinusoid carriers, periodic pulse trains, cyclic prefix, and preambles, etc. These features are unique for each signal type or frame/packet structure. The correlation process is being used to quantize the similarity between two signals. The correlation between the same waveforms produces the largest value. Using this benefit of the correlation characteristics, the periodic feature of the given signal can be the signature for the specific signal type.

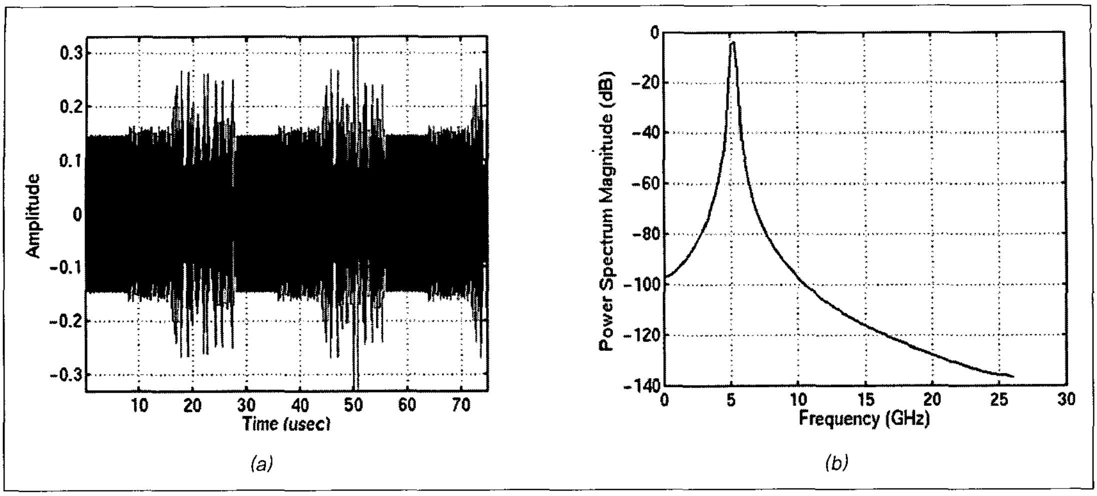
The Analog Auto-Correlation (AAC) is proposed as the fine spectrum sensing technique. Fig. 6 is the functional block diagram of the suggested AAC technique. The building blocks are composed of the analog delay line, the analog multiplier, the analog integrator, the sliding window integrator, and low speed ADC to digitize the calculated analog correlation values.

The input RF signal is delayed by the certain delay value T_d. This delay value T_d is predetermined and unique value for each signal format. The analog correlation between the original input signal $x(t)$ and the corresponding delayed signal $x(t\text{-}T_d)$ is performed by multiplying these two signals and integrating the resulting product. These correlation values are summed by the sliding-window integrator. When the resulting integrator output is greater than the certain threshold, the AAC sensing scheme determines the specific signal type for the input signal.

Since the procedure done at analog domain, whole AAC can enable real-time operation and low power consumption, which are the bottleneck of most of the digital based feature detection technologies. By applying delay and correlation to the input signal, the blind detection is achieved with no need of any known reference signals. This blind detection drastically reduces the hardware burden and the power consumption for the reference signal recovery. Moreover, the AAC technique enhances



⟨Fig. 6⟩ The functional block diagram of the suggested AAC technique.



⟨Fig. 7⟩ The IEEE802.11a - WLAN (OFDM) signal; (a) the waveform and (b) the spectrum.

the spectrum sensing performance with the collaboration with the MRSS technique. Once the MRSS detects the suspicious interferer signal reception, the AAC examines the unique feature for the signal and identifies its specific signal type.

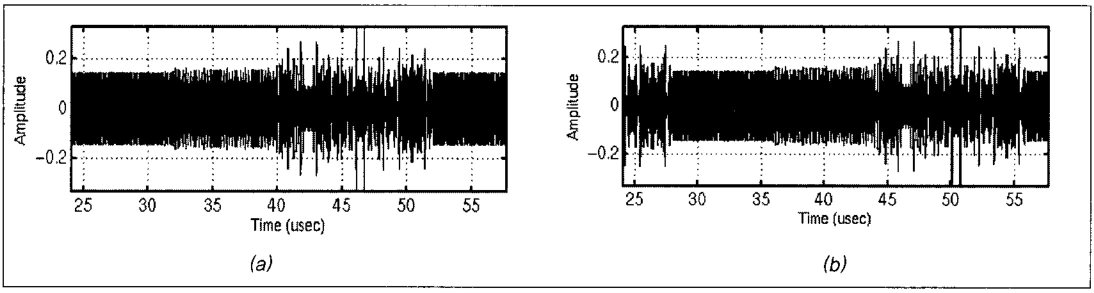
In order to show the proof of the concept, a computer simulation was performed. For the IEEE802.11a - OFDM signal. This signal has the synchronization preambles at the beginning of the frame structure. For the simplicity, only one data OFDM symbol is followed by the preamble. Fig. 7 (a) and (b) show the waveform and the spectrum of the input OFDM signal to be detected with the proposed AAC technique.

The waveforms of the original input signal $x(t)$ and the delayed signal $x(t-T_d)$ shown in Fig. 8 (a) and (b), respectively. The resulting correlation waveform has the consecutive positive values for the preambles. Then, the result of the sliding-window integration has the peaks for the preamble locations as shown in Fig. 9. The correlation for the modulated data symbols has the random values and can be ignored after the sliding-window integration. By comparing the predetermined threshold and delay value with the resulting waveform, the AAC technique can identify the type of the signal.

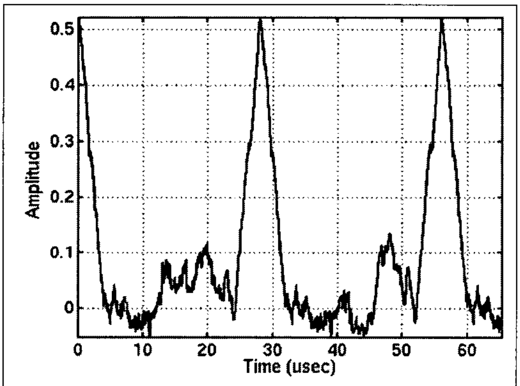
The Cognitive Radio (CR) technology is a promising solution for exploiting the limited spectrum resources. The realization of CR requires two essential features: (i) Wideband Spectrum Sensing, and (ii) Frequency-agile operation.

This paper suggests the CR system architecture comprised of (i) a wideband antenna, (ii) the frequency-agile front-end with wideband and reconfigurable features, (iii) the analog wideband spectrum sensing block with dual stages - the coarse and the fine sensing stages, (iv) the physical layer signal processing block (PHY) and (v) the medium access control block (MAC).

The spectrum sensing technique is the critical



⟨Fig. 8⟩ The correlator input signals. (a) the original input signal $x(t)$ and (b) the delayed signal $x(t-T_d)$



⟨Fig. 9⟩ The waveform of the correlation between the original input signal $x(t)$ and the delayed signal $x(t-T_d)$ (after sliding window integration)

issue for the realization of the CR technology. For the reliable and efficient spectrum usage of the CR link, this spectrum sensing technique must satisfy the requirements such as detection accuracy, sensing speed, power consumption, hardware complexity, flexible resolution, and universal detection performance for the various signal formats.

V. CONCLUSION

In this paper, the spectrum sensing technologies for cognitive radio system, which possibly can be used for interactive broadcasting service. The spectrum sensing technology can be used for finding the locally, temporary unused channel for up-link. The suggested spectrum sensing techniques consisted of dual sensing stages - the coarse and the fine spectrum sensing. These two sensing stages collaborate with each other to enhance the accuracy of the spectrum detection performance. The coarse spectrum sensing technique adopted the wavelet transform to provide the multi-resolution sensing feature - Multi-Resolution Spectrum Sensing (MRSS). This feature realizes the flexible detecting resolution without any hardware burden increase. The fine spectrum sensing exploits the periodic feature of the input signals unique for each modulation format or frame structure. This fine sensing technique uses the beneficial properties of the autocorrelation function - Analog Auto-Correlation (AAC). The simulation for various type of modulation signals, such as FM, ATSC and OFDM, are performed to show the validity of the sensing methods.

참 고 문 헌

[1] Mitola, J., III, "Cognitive radio for flexible mobile multimedia communications," in IEEE Int. Workshop on Mobile Multimedia Communications, 1999.

[2] The Federal Communications Commission (FCC), "Notice for Proposed Rulemaking (NPRM 03 322): Facilitating Opportunities for Flexible, efficient, and Reliable Spectrum Use Employing Spectrum agile Radio Technologies", T Docket No. 03 108, Dec 2003.

[3] "WRAN PHY and MAC Proposal for TDD/FDD," doc.: IEEE 802.22-05/0108r0, http://www.ieee802.org/22/Meeting_documents/2005_Nov/22-05-0108-00-0000_ETRI-SEM-GeorgiaTech_Proposal_Outline.doc

[4] C. K. Chui, An Introduction to Wavelets. New York: Academic, 1992

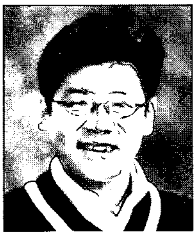
[5] Y. Hur, W. Woo, J. Park, K. Lim, C.-H. Lee, H.S. Kim, and J. Laskar, "A wideband Multi-Resolution Spectrum Sensing (MRSS) Technique for A Cognitive Radio (CR) Access System," in 2006 IEEE Int. Symp. On Circuits and Systems (ISCAS 2006), Kos, Greece, May 2006.

[6] A. Sahai, N. Hoven, R. Tandra, "Some Fundamental Limits on Cognitive Radio", Proc. of Allerton Conference, Monticello, Oct 2004.

필 자 소 개

Kyutae Lim

Kyutae Lim received the B.S., M.S. and Ph.D. degrees from the Hanyang University, Seoul, Korea, in 1991, 1993 and 1996, respectively.
From 1996 to 2000, he has been with the Samsung Advance Institute of Technology, Kiheung, Korea, as a member of technical staff. From 1998 to 1999, he has been with the Communication Research Lab, Tokyo, Japan, as a research fellow.
In Jan 2000, he joined Georgia Institute of Technology as a Senior Research Engineer. Currently he is serving as Associate Director of Technology of Georgia Electronic Design Center (GEDC) in Georgia Tech. Current technical projects that he is leading and co-leading are Cognitive Radio, CMOS Power Amplifier, Digital Transmitter and Software Defined Radio. He is also involving in the IEEE 802.22 standard which utilizes Cognitive Radio concept.
His research interests include the analysis of the electro-magnetic phenomenon, antenna designs, high-frequency/mixed signal system optimization and passive and IC circuit designs for wireless and mixed signal systems. He has authored and co-authored over 100 journal and proceeding papers, holds 2 U. S. patents and the author of two book chapters. Also he has been invited as a speaker for international workshops, conferences and tutorials including International Microwave Conference (IMS) and Electronic Component Technology Conference (ECTC).
Dr. Lim is a member of IEEE Microwave Theory and Technique (MTT), Component, Packaging and Manufacturing Technology (CPMT), and Antennas and Propagation (AP) and Light wave Technology Societies (LT). He is a member of IEEE 802.22 standard committee.



Youngsik Hur

Youngsik Hur (S' 04-M' 06) received the B.S. and the M.S. degrees in Electrical Engineering from Hanyang University, Seoul, Korea in 1993 and 1995, respectively. He received the Ph.D. degree in Electrical Engineering in the Georgia Institute of Technology in 2005. During his Ph.D. studies, he has been working on mixed-signal circuit implementation of equalization and noise cancellation technique for broadband wired and wireless communication applications. Prior to joining Samsung RF IC design center at Georgia Tech., Atlanta, GA in 2006, Dr. Hur was with the Samsung Institute of Advanced Technology, Kiheung, Korea, and subsequently with the Samsung Electronics, Suwon, Korea from 1995 to 2001. During this period, he was working for development of an Orthogonal Frequency Division Multiplexing (OFDM) wireless communication system and a channel characterization of the 60GHz indoor wireless channel. Subsequently, he was leading the system development efforts of Fiber-Optic Security Sensor System project. Dr. Hur' s current research interests include developments of system and IC solutions enabling the convergence of digital broadcasting and broadband wireless data access. Specifically, he is focusing on realizing a Cognitive Radio (CR) technology as a promising solution of coexistence of unlicensed spectrum applications.

Jeong-Suk Lee

- 1987년 2월 : 항공대학교 항공전자공학 (공학사)
- 1991년 2월 : 항공대학교 항공전자공학 (공학석사)
- 2002년 8월 : 항공대학교 항공전자공학 (공학박사)
- 2005년 3월~현재 : 삼성전기 중앙연구소 Wireless Solution Lab.
- 주관심분야 : GPS, Kalman Filtering, UWB system, Cognitive Radio

Kihong Kim

Chang-Ho Lee

Chang-Ho Lee (M' 01) received his B.S. and M.S. degree in electrical engineering from Korea University, Seoul, Korea, in 1989 and 1991, respectively, and his M.S. and Ph.D. degree in electrical and computer engineering from Georgia Institute of Technology, Atlanta, Georgia, in 1999 and 2001, respectively. He was a research engineer with Dacom Corporations, Korea, from 1994 to 1996. In 2000, he joined RF Solutions, Inc. Norcross, Georgia, where he was a staff engineer. In 2003, he joined Georgia Institute of Technology as a research faculty. From 2005, he is a director of Samsung RFIC Design Center at Georgia Institute of Technology. His research interest includes satellite/wireless communication system design, and design/characterization of the transceiver RFICs in GaAs devices and Si-based CMOS/SiGe HBT processes, as well as LTCC/MLO-based multilayer multichip modules development for wireless communication applications. His current research is related to the low power reconfigurable front-ends design for cognitive radio applications.

Hak-sun Kim

- 1986년 2월 : 항공대학교 항공전자공학 (공학사)
- 1990년 2월 : 항공대학교 항공전자공학 (공학석사)
- 1993년 8월 : 항공대학교 항공전자공학 (공학박사)
- 1993년 3월~ : 한밭대학교 정보통신전문대학원 교수
- 2005년 3월~현재 : 삼성전기 중앙연구소 Wireless Solution Lab 연구위원(상무)
- 주관심분야 : UWB system, Software Radio, Cognitive Radio

Joy Laskar

Dr. Joy Laskar received the B.S. degree (Computer Engineering with Math/Physics Minors, highest honors) from Clemson University in 1985. He received the M.S. and the Ph.D. degrees in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1989 and 1991 respectively. Prior to joining Georgia Tech in 1995, Dr. Laskar has held faculty positions at the University of Illinois and the University of Hawaii. At Georgia Tech, he holds the Joseph M. Pettit Professorship of Electronics, is the Director of Georgia' s Electronic Design Center, and heads a research group of 25 members with a focus on integration of high frequency mixed-signal electronics for next generation wireless and wired systems. He has authored or co-authored more than 350 papers, several book chapters (including three textbooks in development), numerous invited talks and has more than 25 patents pending.

Most recently his work has resulted in the formation of two companies. In 1998 he co-founded an advanced WLAN IC Company: RF Solutions, which is now part of Anadigics (Nasdaq: Anad). In 2001 Dr. Laskar co-founded a next generation analog CMOS IC company: Quellan which is developing collaborative signal processing solutions for the enterprise, video, storage and wireless markets.

He is a 1995 recipient of the Army Research Office' s Young Investigator Award, a 1996 recipient of the National Science Foundation' s CAREER Award, the 1997 NSF Packaging Research Center Faculty of the Year, the 1999 co-recipient of the IEEE Rappaport Award (Best IEEE Electron Devices Society Journal Paper), the faculty advisor for the 2000 IEEE MTT IMS Best Student Paper award, 2001 Georgia Tech Faculty Graduate Student Mentor of the year, recipient of a 2002 IBM Faculty Award, the 2003 Clemson University College of Engineering Outstanding Young Alumni Award, the 2003 recipient of the Outstanding Young Engineer of the Microwave Theory and Techniques Society and he has been named IEEE Fellow from 2005. For the 2004-2006 term, Professor Laskar has been appointed an IEEE Distinguished Microwave Lecturer for his seminar entitled "Recent Advances in High Performance Communication Modules and Circuits".