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Welcome Message from General Chairs

It is our great pleasure to welcome you to the CrownCom 2008, the Third International Conference on Cognitive Radio Oriented Wireless Networks and Communications. The series of CrownCom conferences, previously held in Greece-Mykonos Island (2006) and USA-Orlando (2007), has become a major event attracting more renowned researchers, engineers and technical professionals from a wide array of industrial, governmental agencies as well as academic and research institutions.

CrownCom aims to provide a platform for academics, research engineers, corporate executives and policy makers to present and discuss state-of-art research and development results, to enhance the knowledge base and to chart out future roadmap for cognitive radio networks and technologies. This year, we have received an overwhelming response of papers from all over the world and selected papers for presentation in various topics, including spectrum policy / regulation, dynamic spectrum access / management, TV white space, network security, spectrum sharing, algorithm / signaling / protocol design, spectrum sensing, application-oriented architecture and cognitive radio prototype platforms. We have also prepared three keynote sessions, two special sessions and one panel session for renowned experts to express their diverse views on cognitive radio networks from the perspectives of regulators, operators, vendors and academia. In addition, six half-day tutorials, by prominent researchers and practitioners around the world, covering a wide variety of exciting themes in cognitive radios, will provide all participants a valuable opportunity to jump start and acquire the fundamental knowledge and information.

Putting together CrownCom 2008 in mere nine months was a team effort and more. We are blessed to have an organizing committee who constantly display diligence and dedication in each of their own individual functional responsibilities. In addition, we would like to express our gratitude to the TPC, reviewers and authors for their keen contribution to the mind-stimulating technical program; ICST and the steering committee for their guidance and advice. Last but not least, our special thanks also go to Huawei, our diamond sponsor, for their strong and keen support.

Lastly, we wish that you have a fruitful experience in CrownCom 2008 and enjoyable moments during your stay in Singapore. Together, let's move cognitive radio from imagination to reality!

Francois Chin
Institute for Infocomm Research, A*STAR, Singapore

Geok-Leng Tan
Infocomm Development Authority, Singapore

Message from TPC Chairs

On behalf of the technical program committee (TPC), we would like to welcome you to CrownCom 2008 – The Third International Conference on Cognitive Radio Oriented Wireless Networks and Communications! As an annual forum, CrownCom provides participants a platform to exchange information on the progress of research and development in cognitive radio networks. Leading experts from industry, academia and regulatory bodies all have their share in making the event a truly quality one.

This year we received 156 paper submissions. After peer and independent review, we have accepted 98 high quality papers, which include 27 invited papers. The papers cover a broad range of important and timely issues from spectrum policy, spectrum sensing, cognitive wireless transmission, cognitive MAC, to security issues in cognitive radio networks and cognitive radio prototyping. These papers have been grouped into 18 technical sessions, of which there are two special sessions: one on spectrum-aware routing, and the other on commercialization of cognitive radio system for white space applications. We have also taken a number of measures, including keynotes, panels, and tutorials, to further facilitate the effective exchange of information between the participants.

The final technical program is the result of the dedication and effort of many people. We are deeply indebted to all of our TPC members, as well as our reviewers, who have greatly contributed to the success of the CrownCom 2008 paper review process. Many thanks should be given to our keynote and invited paper speakers who will present their work in this conference. We are grateful to the conveners of the special sessions - Jie Chen, Anh Tuan Hoang and Ktutae Lim, for proposing interesting topics for the special sessions.

We believe that CrownCom 2008 will be a rewarding and memorable experience for every participant. Moreover, we hope that you will find time to enjoy the attractions and activities in Singapore.

We are looking forward to seeing you at CrownCom 2008!

Ying-Chang Liang
Institute for Infocomm Research, A*STAR, Singapore

Vahid Tarokh
Harvard University, USA

Douglas Sicker
University of Colorado, USA

Qian Zhang
Hong Kong University of Science and Technology, China

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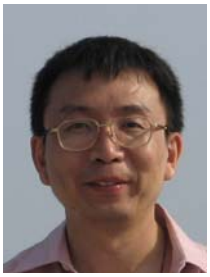
General Chairs

Francois Chin *(I²R, Singapore)*

Geok Leng Tan *(IDA, Singapore)*

General Vice Chair



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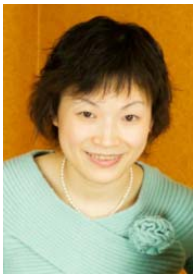

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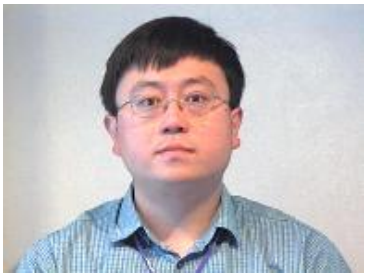

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Ye (Geoffrey) Li
Allen B.MacKenzie
Yang Yang
Yonghong Zeng
Hitoshi Yoshino
Zhi Ding
Zhu Han
Zhi Tian

MEETING INFORMATION

Conference Location

Holiday Inn Atrium Singapore is a spectacular 27 storey atrium style hotel strategically located at the crossroad of Outram and Havelock Roads. It is just a short drive from Shenton Way financial centre, fascinating Chinatown and the fashionable Orchard Road shopping belt.

Across from the hotel is the island's renowned Singapore River where entertainment spots bring vibrancy to the nightlife at Clarke Quay and Boat Quay.

Landmarks

- 5 minutes to Shenton Way Financial Centre, Chinatown and Great World City Shopping Mall.
- 10 minutes to Orchard Road.
- 25 km to Changi Airport.
- 1.5 km to the nearest MRT station (Outram Park).

Address
317 Outram Road
Singapore, 169075 Singapore
Front-desk: +65-67330188
Fax: +65-67330989

CONFERENCE PROGRAM

Starting Time	15 May (Thurs)			16 May (Fri)			17 May (Sat)		
900	Tutorial 1A	Tutorial 1B	Tutorial 1C	Keynote #3			SM1	SM2	SM3
920									
940									
1000				Panel Discussion					
1020									
1040									
1100				Tea Break			Tea Break		
1120				FM1	FM2	FM3	SM4	SM5	SM6
1140									
1200									
1220	Lunch								
1240									
1300				Lunch			Lunch		
1320	Opening Speech								
1340	Keynote #1								
1400				FA1	FA2	FA3	Tutorial 2A	Tutorial 2B	Tutorial 2C
1420									
1440	Keynote #2								
1500									
1520									
1540	Tea Break								
1600	TA1	TA2	TA3	Tea Break					
1620				FA4	FA5	FA6			
1640									
1700									
1720									
1740									
1800	End			Banquet			End		

Keynote Speakers

Keynote 1: Are we really running out of radio frequency spectrum?

(13:40 - 14:40, 15 May 2008)

Geok-Leng Tan
Chief Technology Officer
Infocomm Development Authority, Singapore

Abstract

One look at the radio spectrum allocation chart of any country is likely to show that most of the spectrum below 6GHz has already been allocated. This has given rise to the perception that radio frequency spectrum is in short supply. But, are we really running out of radio frequency spectrum?

Analysis of intensity of radio spectrum usage over frequency, time and space by various groups in the United States and the UK has shown that in actuality, the radio spectrum is only used about 15% of the time on an average basis.

IDA Singapore in collaboration with the Institute for Infocomm Research (I^2R) has conducted a short study to look at the intensity of use of radio spectrum in Singapore. This study, which is by no means comprehensive, does give a snapshot of spectrum usage in a certain area of Singapore. Our measurement results show that the average spectrum utilization in the frequency band from 80MHz to 5.85GHz is below 5%. Furthermore, we can clearly see that certain bands are completely free because they are set aside because of cross-border spectrum coordination with our neighbouring countries.

Given that the actual spectrum use intensity is relatively low in US, UK and now demonstrated, albeit on a sample basis in Singapore, it may be possible to explore the use of cognitive radio technologies to intensify the use of spectrum, provided it does not cause interference to the primary users. I look forward to learning about these cognitive radio technologies from the speakers at this conference.

Biography

Geok-Leng Tan is the Chief Technology Officer and Senior Director (Technology & Planning) at the Infocomm Development Authority (IDA) of Singapore. He is responsible to provide technical leadership and strategic planning at IDA and to communicate IDA's vision for infocomm directions to stakeholders across Singapore.

Before joining IDA, Dr. Tan worked in Motorola developing pagers and walkie-talkies for the US and global market. After Motorola, he took up a scholarship to pursue a PhD in Digital Communications at Cambridge University, UK and subsequently worked for Scientific Generics, a Cambridge-based technology consulting company working in area of communications. On his return to Singapore, Dr. Tan was involved in several technology start-ups that provided consultancy, wireless communications product development and product miniaturization using advanced packaging technologies.

He holds a B.Sc in Electronics and Communications from Birmingham University and a Ph.D in Digital Communications from Cambridge University, UK. He is currently an Adjunct Associate Professor at the School of Electrical and Electronic Engineering at the Nanyang Technological University, Singapore.

Keynote 2: Spectrum trading (14:40 – 15:40, 15 May 2008)

Sverrir Olafsson
BT Mobility Research Centre, UK

Abstract

The rapid growth in the density of wireless access devices, accompanied by increasing heterogeneity in wireless technologies, requires adaptive allocation and reallocation of spectrum. The traditional allocation of spectrum does not allow for its flexible utilisation. These shortcomings call for new ways to access spectrum, for example through opportunistic spectrum usage and spectrum trading.

As technologies emerge on ever-faster time-scales spectrum trading on shorter and shorter time-scales will eventually create the basis for a real-time and liquid market in spectrum. This process will be accompanied by rapidly developing means to dynamically price the use of spectrum and provide the basis for transparency in pricing. In these liquid markets users can acquire the spectrum that best suits their needs and they will pay for it an economic price determined collectively by the market.

We will discuss scenarios where spectrum trading will happen through brokers who continuously monitor the utilisation of different frequency bands and negotiate between those who need to buy or sell spectrum. The brokers may also have the role of a market maker and as such may be required to continuously quote the price of spectrum bands on the basis of their supply and demand situation.

We will discuss scenarios where spectrum could become an asset class not only traded for hedging purposes but perhaps for speculation as well. Major investment funds may want to include spectrum in their investment portfolios for enhanced diversification and risk management.

Biography

Sverrir Olafsson is a Chief Researcher at British Telecommunications Research Laboratories in the UK. He is also a Professor in Risk Management at Reykjavik University in Iceland.

In recent years his main focus has been on modelling utilisation of spectrum in wireless systems by the implementation of distributed optimisation techniques. With his team he has developed new approaches to dynamic power control with particular focus on

stability conditions in large wireless systems. Recently this study has been extended to the development of interactive algorithms for channel optimisation and power control.

Previously Dr. Olafsson worked on self-organisation and game theory and applied it to open and dynamic service networks. His work on the usage of evolutionary game theory attracted considerable attention and has been worked on and extended by various PhD students. Dr. Olafsson has also worked on stochastic complexity and long-range correlations in data networks.

More recently his attention has been drawn to the wider aspects of spectrum management with particular attention on the commoditisation and securitisation of spectrum and spectrum trading. Of particular interest to him are questions such as: How do we price spectrum and how can network operators and service provider secure their timely access to spectrum? In his analysis he has drawn on hedging strategies based on derivative securities now widely and successfully used for the trading of conventional commodities in the financial markets.

Dr. Olafsson received his PhD in mathematical Physics from the University of Karlsruhe in 1983. He holds five patents and has over 80 refereed publications.

Keynote 3: Intelligence in the Network (09:00 – 10:00, 16 May 2008)

Joseph B. Evans
University of Kansas, USA

Abstract

The ongoing revolution in computing and communications technology has changed many of the foundational assumptions of today's network architectures. The challenges of the increasingly complex networking environment - particularly wireless networking - make novel approaches to operations, control, and management of radios and networks imperative. In this talk, a multi-layered approach to solving wireless networking problems using cognition will be discussed. By incorporating collaborative sensing, control and management, and learning at multiple layers and on different time scales, wireless networks can be made to adapt to the dynamics caused by radio communications and mobility. This approach will be illustrated through cognitive examples at the radio layer, at the network layer, and at the management and control tier.

Biography

Joseph B. Evans is the Deane E. Ackers Distinguished Professor of Electrical Engineering & Computer Science at the University of Kansas (KU). He is also the Director of Research Information Technology for KU, reporting to the Vice Provost for Research. Dr. Evans served as a Program Director at the National Science Foundation (NSF) from 2003 to 2005. At NSF, he had oversight responsibility for over $70 million in multi-organizational networking research efforts in wireless networking, cybersecurity, optical networking, and scientific applications. Further, he was responsible for over $50 million in new research and infrastructure awards in newly created programs. He was a co-founder and member of the Board of Directors of NetGames USA, Inc., a network gaming company acquired by Microsoft in 2000; XBox Live, Microsoft's Internet gaming service, utilizes the company's technology. Dr. Evans has been involved in creating several other technology companies, including a start-up that has developed and deployed TIGR (Tactical Ground Reporting System) for DARPA and the US Army. He has been a researcher at the Olivetti & Oracle Research Laboratory, Cambridge University Computer Laboratory, USAF Rome Laboratories, and AT&T Bell Laboratories. Dr. Evans' recent activities include participation in the NSF Global Environment for Network Innovations (GENI) effort, serving as a member of the planning group and most recently as Substrate Working Group co-chair. He has been

extensively involved in cognitive radio networking research, including systems prototyping and foundational science to inform the policy debate over use of radio spectrum white spaces. Dr. Evans received the B.S.E.E. degree from Lafayette College in 1983, and M.S.E., M.A., and Ph. D. degrees from Princeton University in 1984, 1986, and 1989, respectively.

Panel Discussion

Cognitive Radio Networks: Imagination or Reality?

(10:00 – 11:00, 16 May 2008)

Since coined by Joseph Mitola in 1999, cognitive radio networks have witnessed a tremendous upsurge in the academic research with the expectation that the scarce wireless spectrum which is becoming more and more expensive to acquire will be shared in a more flexible and efficient fashion in cognitive radio networks.

Recently the academic conceptual ideas and studies have been migrating rapidly to cognitive radio system designs in industry, e.g. IEEE 802.22, P1900, IEEE 802.16h, IEEE 802.11y standards, facilitated by the policy makers who have provided the necessary regulatory playground. Cognitive radio networking is viewed as an promising technology introducing new communications and networking models for the whole wireless world, creating better business opportunities for the incumbent operators and new technical dimensions for smaller operators, and helping shape an overall more efficient approach regarding spectrum requirements and usage in next generation wireless networks. It possesses a huge potential to become a true paradigm shifting technology in our telecommunications field.

However, cognitive radio networking so far is still a big dream. In the reality, there are many challenges to overcome before it really takes off. It is still unclear how far we are from the real realization of this opportunism exploited by cognitive radios? Are there any opportunities for immediate and practical applications? How long are we going to wait to see the first product?

A distinguished panel of experts ranging from operators, industry and policy makers, and academia will shed some light on the issues with focus on policy, economics, standards, applications, technologies and deployment aspects of cognitive radio networks. Each of the panelist will be giving a short presentation to identify a couple of areas they deem more critical, more promising or merely more interesting to the realization of the cognitive radio networks before the heat debate.

Tutorials

Tutorial 1A: Cognitive Radio as an Advanced Radio Resource Management

(09:00 – 12:20, 15 May 2008)

Speaker

Prof. Seiichi Sampei, Osaka University, Japan

Abstract

Cognitive Radio is a new concept for the future Information and telecommunications networks, and it is expected as a breakthrough for shortage of spectrum as well as a technique to guarantee Quality of Services for each user in ubiquitous and heterogeneous networks. In this tutorial, we will focus mainly on how the cognitive radio should be introduced in wireless communication networks, especially, as an advanced radio resource management. In this tutorial, after brief discussion on the basic concept of cognitive radio, the concept of radio resource management is explained and then what is the advanced spectrum sharing based on cognitive radio will be explained. Finally, relationship between the cognitive radio and heterogeneous networks will also be explained.

Biography

Seiichi Sampei received the B.E., M.E. and Ph.D. degrees in electrical engineering from Tokyo Institute of Technology, Japan, in 1980, 1982 and 1991, respectively. From 1982 to 1993, he was engaged in the development of adjacent channel interference rejection, fast fading compensation and M-ary QAM techniques for land-mobile communication systems, as a researcher in the Communications Research Laboratory, Ministry of Posts and Telecommunications, Japan. During 1991 to 1992, he was at the University of California, Davis, as a visiting researcher. In 1993, he joined the Faculty of Engineering, Osaka University, and he is currently a Professor in the department of Information and Communications Technology, Osaka University, where he has developed adaptive modulation, intelligent radio transmission/access, and cognitive wireless networking techniques. He received the Shinohara Young Engineering Award, and the Achievements Award from the IEICE (Institute of Information and Communication Engineers), the Telecom System Technology Award from the Telecommunication Advancement Foundation, and the DoCoMo Mobile Science Award from Mobile Communication Fund. He is a member of the Institute of Image Information and Television Engineers (ITE), and a Fellow of the IEEE and Institute of Electronics, Information and Communication Engineers (IEICE).

Tutorial 1B: Cognitive Wireless Networks

(09:00 – 12:20, 15 May 2008)

Speakers

Prof. Petri Mähönen, RWTH Aachen University, Germany
Janne Riihijärvi,RWTH Aachen University, Germany
Marina Petrova, RWTH Aachen University, Germany

Abstract

This tutorial starts by giving a brief historical background on the cognitive radios. We describe what is meant by spectrum agile radios and by full cognitive radios ("Mitola Radios"). From cognitive radios we then move on to basic concepts of cognitive wireless networks. The emphasis will be on covering recent research results and remaining key research challenges towards creation of such networks. We cover briefly game theory and other classical approaches, but our focus here will be on the use of metaheuristics and machine learning algorithms for full cross-layer and network wide optimization. We shall also discuss in some detail applications of topology and geometry information in the optimization process. As a part of the discussion, a brief introduction to modern spatial statistics techniques will be provided. The tutorial is emphasizing architectural concepts and emerging new methodologies. The tutorial also provides attendees with knowledge of the most important concepts and open research questions in this emerging field. As such it is also suited for beginning graduate students.

Biographies

Petri Mähönen is currently a full professor and holds Ericsson Chair of Wireless Networks at the RWTH Aachen University in Germany. Before joining to RWTH Aachen in 2002, he was a research director and professor at the Centre for Wireless Communications and the University of Oulu, Finland. He has studied and worked in the United States, United Kingdom and Finland. He has been a principal investigator in several international research projects, including initiating and leading several large European Union research projects. Dr. Mähönen has published ca. 150 papers in international journals and conferences and has been invited to deliver research talks at many universities, companies and conferences. He is a senior member of IEEE and ACM, and fellow of RAS. He is inventor or co-inventor for over 20 patents or patent applications. He has been particularly active in cognitive wireless network research and has been serving in different roles in relevant cognitive communications domain conferences, such as DySPAN, CogNet and CrownCom. He has been also guest-editor for several special issues in the field. He is currently also a research area coordinator and one of the principal investigators for a newly formed Ultra High Speed Mobile Information and Communication (UMIC) research cluster at RWTH, which is one of the German national excellence clusters supported by the Federal Government of Germany established in 2006. One of the research domains in UMIC cluster is also cognitive radio network technologies.

Janne Riihijärvi works as a senior research scientist at the Department of Wireless Networks at RWTH Aachen University. Before joining RWTH he worked in a variety of research projects on wireless networks at VTT Electronics and at the Centre for Wireless Communications at University of Oulu. His research interests have lately been in applications of techniques from spatial statistics and stochastic geometry on characterization of wireless networks, embedded intelligence in general, use of metaheuristics in optimizing component-oriented systems, and various frequency assignment and topology control problems. He has also worked on various enabling technologies for cognitive wireless networks, including participating into the development of the Unified Link-Layer API as well as different localization and tracking frameworks. As a part of his research work he has participated extensively into international research projects as well as research projects carried out in collaboration with the industry.

Marina Petrova works as a chief research scientist at the Department of Wireless Networks at the RWTH Aachen University. She graduated in Electronics and Telecommunications engineering from the University of St. Cyril and Methodius, Skopje, Macedonia. Her research interests are focused on cognitive wireless networks, cognitive radios and adaptive wireless systems technologies. The topic of her Ph.D. thesis work at the RWTH Aachen has been also the multi-parameter optimization methods for cognitive radio networks. As part of her research work she has participated in the several international cooperative projects and industry projects in the field of wireless communications and cognitive radios. In Aachen she has also lead the research work that has been done towards the prototype implementation of gnu Radio based cognitive resource manager for cognitive radios. She has also served in technical program and organizing committees of conferences, among those IEEE DySPAN, IEEE Crowncom, the leading conferences in the field of cognitive radios and networks.

Tutorial 1C: Challenges of Cognitive Radios in the physical layer

(09:00 – 12:20, 15 May 2008)

Speakers

Prof. Aarne Mämmelä, VTT Technical Research Centre of Finland
Marja Matinmikko, VTT Technical Research Centre of Finland

Abstract

This tutorial will emphasize system level aspects of cognitive radios from the physical layer point of view. A brief history and the state of the art of cognitive radios and the underlying spectrum regulatory framework will be given, some conceptual analysis will be made, and the major performance metrics will be covered. We will explore the challenges of cognitive radios including limited awareness (no "sense of sight", finite probability of detection), hidden terminal problem, wide bandwidth (delays in sensing with existing components), emission to adjacent bands (spectral sidelobes, nonlinear properties), control bottleneck, and complexity. We will give examples of the challenges with an emphasis on the physical layer aspects and their effect on the cognitive radio system.

Biographies

Aarne Mämmelä received the degree of Ph.D. (with distinction) from the University of Oulu in Finland in 1996 in the field of adaptive receivers in wireless telecommunications. From 1982 to 1993 he was with the University of Oulu. In 1993 he joined VTT Technical Research Centre of Finland in Oulu. Since 1996 he has been a research professor of digital signal processing in wireless telecommunications at VTT. Since 2000 he has also been an adjunct professor (docent) at the Helsinki University of Technology and in addition since 2004 at the University of Oulu. He is interested in system level aspects in cognitive radios and nonlinear phenomena, especially in the physical layer.

Marja Matinmikko was born in Rovaniemi, Finland, in 1979. She received her M.Sc. degree in industrial engineering and management, and Lic.Sc. degree in telecommunications from the University of Oulu, Oulu, Finland, in 2001 and 2007, respectively. She has been working at VTT Technical Research Centre of Finland in Oulu, Finland, since 2001 as a research scientist. She participated in the ITU-R standardization activities on the spectrum requirements of IMT-Advanced in preparation for the WRC-07, acted as the editor of Recommendation ITU-R M.1768 describing the spectrum requirement calculation methodology for IMT-Advanced, and authored several book chapters on the topic. Her current research interests include IMT-Advanced systems, cognitive radio networks and spectrum topics.

Tutorial 2A: An Introduction to Cognitive Radio and Dynamic Spectrum Sharing

(14:00 – 18:00, 17 May 2008)

Speakers

Prof. Friedrich K. Jondral, University of Karlsruhe (TH), Germany
Dr. Ivan Cosovic, NTT DoCoMo Euro-Labs, Germany
Dr. Gunther Auer, NTT DoCoMo Euro-Labs, Germany

Abstract

Cognitive radio (CR) shows many facets. It has some awareness as well as some knowledge that is stored in data bases from where it may be retrieved when needed. Of course, the acquisition, the storage, the retrieval and the interpretation of knowledge are interesting processes. The engineer, however, is mainly interested how CRs can help to overcome transmission problems. The most prominent of these problems is to cope with the complicated mobile radio channels in order to make efficient use of the scarce frequency resources.

The first part of this tutorial discusses how CRs may be employed in dynamic spectrum sharing. Since CRs are built on software defined radios (SDRs), this technology is reviewed too from a commercial as well as from a military system's view. A realistic projection of future CR applications in communications engineering is given.

The second part of this tutorial is mainly devoted to centralized spectrum trading approaches and design of MAC protocols in dynamic spectrum sharing system. Furthermore, views on the outcome of the World Radio Communication Conference 2007 (WRC-07) are given, and some European activities on spectrum sharing are presented.

Biographies

Friedrich K. Jondral received the Dipl.-Math. and Dr.rer.nat. degrees in mathematics from the Technische Universität Braunschweig (Germany) in 1975 and 1979, respectively. During the winter semester 1977/78 he was a visiting scientist at the University of Nagoya (Japan). From 1979 to 1992 he was with AEG-Telefunken (now European Aeronautic Defence and Space Company, EADS), Ulm (Germany), where he held various research, development, and management positions. During this time he also lectured on courses in applied mathematics at the Universität Ulm where he was appointed Adjunct Professor in 1991. Since 1993 he has been full Professor and Head of the Institut für Nachrichtentechnik at the Universität Karlsruhe (TH), Germany.

Ivan Cosovic received the Dipl.-Ing. degree in electrical engineering from the University of Belgrade, Serbia, in 2001, and the Ph.D. in electrical engineering (with highest honors) from the Johannes Kepler University, Linz, Austria, in 2005. From 2002 to 2006, he was with the Institute of Communications and Navigation, German Aerospace Center (DLR),

Wessling, Germany. He joined DoCoMo Euro-Labs, Munich, Germany, in 2006. He is a Guest Editor for the EURASIP Journal on Wireless Communications and Networking special issue on cognitive radio and dynamic spectrum sharing. He received DLR Science Award 2006 (DLR-Wissenschaftspreis 2006) of the German Aerospace Center. His research interests include spectrum sharing, cognitive radio and multi-carrier schemes for wireless communications systems.

Gunther Auer received the Dipl.-Ing. Degree in Electrical Engineering from Universität Ulm, Germany, in 1996, and the Ph.D. degree from the University of Edinburgh, UK, in 2000. From 2000 to 2001 he was a Research and Teaching Assistant with Universität Karlsruhe (TH), Germany. Since 2001 he is with NTT DoCoMo Euro-Labs, Munich, Germany. His research interests include self-organized networks and multi-carrier based communication systems, including medium access, cross-layer design, channel estimation and synchronization techniques.

Tutorial 2B: Cognitive MIMO Mesh Network for Spectrum Sharing

(14:00 – 18:00, 17 May 2008)

Speakers

Prof. Kei Sakaguchi, Tokyo Institute of Technology, Japan
Prof. Takeo Fujii, The University of Electro-Communications, Japan

Abstract

Concept of cognitive radio is very wide from multi-mode systems to dynamic spectrum access with aggregating the plural spectrum sets for achieving high-speed and flexible wireless communications. As one of the key technologies for cognitive radio is a spectrum sharing. One practical spectrum sharing example is unlicensed wireless systems using 2.4GHz. In the conventional spectrum sharing system, only the simple carrier sense is a technique for mitigating the inter-system interference in the spectrum. To improve the spectrum efficiency and the flexibility of the communication over the existing wireless networks, multi-hop mesh networks are suitable. This is because multi-hop networks can keep minimizing giving interference toward the surrounding users by selecting the route and by controlling the power.

However, multi-hop networks increase the intra-spectrum interference due to share the spectrum their own nodes. In this tutorial, we focus on multi-hop mesh networks to mitigate the intra-system interference and inter-system interference for realizing the useful high-speed wireless communications over the existed primary systems. We have two main topics. First one is intra spectrum sharing by using MIMO mesh network. Second one is inter spectrum sharing by using MAC, routing and power control technologies on the secondary multi-hop networks under the existence of the primary system. By integrating these two topics, we can give you a novel secondary wireless distributed network concept overlaying primary wireless networks.

Biographies

Kei Sakaguchi was born in Osaka, Japan, on November 27, 1973. He received the B.E. degree in electrical and computer engineering from Nagoya Institute of Technology, Japan, in 1996, the M.E. degree in information processing from Tokyo Institute of Technology, Japan, in 1998, and the Ph.D. degree in electrical and electronic engineering from Tokyo Institute of Technology in 2006. From 2000, he is an Assistant Professor at Tokyo Institute of Technology. He received the Young Engineer Awards from IEICE and IEEE AP-S Japan chapter in 2001 and 2002 respectively, and the Outstanding Paper Awards from SDR Forum and IEICE in 2004 and 2005 respectively. His current research interests are MIMO propagation measurements, MIMO communication systems, and software defined radio. He is a member of IEICE and IEEE.

Takeo Fujii received his B.E., M.E. and Ph.D. degrees in Electrical Engineering from Keio University, Yokohama, Japan, in 1997, 1999 and 2002, respectively. From 2000 to 2002, he was a research associate in the Department of Information and Computer

Science, Keio University. From 2002 to 2006, he was an assistant professor in the Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology. Since 2006, he has been an associate professor in Advanced Wireless Communication Research Center (AWCC), The University of Electro-Communications. His current research interests are in broadband wireless communication systems and packet data wireless communication systems. He received Best Paper Award in IEEE VTC 1999-Fall, 2001 Active Research Award in Radio Communication Systems from IEICE technical committee on RCS, 2001 Ericsson Young Scientist Award and Young Researcher's Award from the IEICE in 2004. He is a member of IEICE and IEEE.

Tutorial 2C: Cognitive Radio Networks – Opportunities, Challenges and Technologies for Dynamic Spectrum Access of TV Band White Spaces

(14:00 – 18:00, 17 May 2008)

Speakers

Dr. Carlos Cordeiro, Intel Corporation, USA
Dr. Sai Shankar N, Broadcom Corporation, USA

Abstract

Static spectrum allocation has resulted in low spectrum efficiency in licensed bands and poor performance of radio devices in crowded unlicensed bands. To overcome the above problem, we exploit the concept of spectral agility (a unique functionality of cognitive radio) such that radio devices can dynamically utilize idle spectral bands. Previously, the Federal Communication Commission (FCC) allocated frequency bands of the spectrum to a particular application, like TV, AM/FM radio systems, and cellular phone systems. The bands allocated to these applications are called licensed frequency bands. Consequently, existing solutions for wireless multimedia streaming concentrate on a single technology like wireless LAN or wireless PAN, Cellular, etc. However, it is expected that the necessary radio system resources will not be sufficient in the future, due to the limited radio spectrum in the current unlicensed frequency bands which are highly utilized by current consumer electronic devices. This motivates the need for CRs.

CRs have been receiving increasing attention in academia, industry, and government. What many people do not realize though is that early forms of CRs have been around us for years now, such as Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS) defined for the 5GHz unlicensed band to avoid interference with radar signals. However, the difference between now and then is that the scope has been expanded to include dynamic reuse of other vacant licensed bands. Such is the case with the TV bands, where studies indicate that up to 90% of that spectrum is not utilized. As a consequence, regulatory bodies (e.g., the FCC in the USA, OFCOM in the UK, etc.) are considering the deployment of wireless technologies that can identify if a TV channel is available or not, and that would access a particular TV band without causing harmful interference to the TV service. CR technologies promise to enable efficient spectrum (re)use without causing harmful interference to incumbent users.

In this tutorial we look at various aspects related to the application, research and development of CRs in the particular case of TV bands, including architectures of cognitive radios, spectrum sensing, performance, protocols and algorithmic challenges. We will also cover ongoing industry activities in this area, including the IEEE 802.22 Working Group which is formulating the first worldwide standard for CR-based operation in vacant TV channels. This tutorial will also provide insights into future directions and evolution of this exciting field, and will review different open issues and research challenges that will hopefully catalyze new research efforts. We conclude the tutorial with a review of the aspects that need to be addressed to enable a smooth transition of various wireless multimedia applications to cognitive radio networks, and

how the industry and academia have to evolve to meet the goal set by regulatory bodies as well as make CR techniques as true market-driven approaches.

Biographies

Carlos Cordeiro is a Research Scientist in the Communications Technology Lab of Intel Corporation. Before joining Intel Labs, he worked for Philips Research North America and Nokia Research Center. Dr. Cordeiro has been involved with CRs for a number of years, which includes active participation in the IEEE 802.22 standardization effort as well as in building spectrum sensing and data communication CR prototypes for the TV bands. Due to his contributions to this area, he was selected by the IEEE as the worldwide 2007 New Face of Engineering and was the recipient of the IEEE Region 1's 2007 Technological Innovation Award for "Pioneering Contributions to the Advancement and Design of Cognitive Radio based Wireless Technologies." Dr. Cordeiro was also part of the team that received the 2007 Frost & Sullivan Excellence in Research of the Year Award in the field of cognitive networks. He is the co-founder and Industry Liaison to the IEEE ComSoc Technical Committee on Cognitive Networks and was the Guest Editor of the first IEEE J-SAC issue on CRs. He is the author of the textbook Ad Hoc and Sensor Networks: Theory and Applications published by World Scientific Publishing in early 2006. His interests include the IEEE 802 family of standards, cognitive radios, millimeter wave technologies, MIMO, and ad hoc and sensor networks. Dr. Cordeiro has served as Chair and TPC member of various meetings, has published over 75 papers in the wireless area alone, and holds numerous patents.

Sai Shankar N received his PhD degree from the department of Electrical Communication Engineering from Indian Institute of Science, Bangalore, India in the area of ATM networks. In 1998, He was awarded the German Fellowship, DAAD, in the department of mathematics, University of Kaiserslautern, Germany to work on queuing approaches in manufacturing. In 1999, he joined Philips Research, Eindhoven, the Netherlands, where he served as Research Scientist in the department of New Media Systems and Applications. He worked on various problems involving Hybrid, Fiber, Co-axial Cable (IEEE 802.14) Networks and IP protocols and provided efficient algorithms to improve protocol and buffer efficiency. In the year 2001 he joined Philips Research USA, Briarcliff Manor, NY as "Senior Member Research Staff" and worked actively in the area of WLANs and WPANs. He was the prime contributor of the wireless LAN standard in shaping QoS (TXOP, TSPEC, Admission Control and Simple Scheduler) related issues in the IEEE 802.11e Working Group that has been incorporated in IEEE 802.11e standard. He was also an active participant in the Ultra Wide Band (UWB) MAC working group of Multi-Band OFDM Alliance (MBOA) and is one of the prime contributor and author of the new MBOA MAC. To this end he was nominated as one of the five finalists by Electronic Engineering Times (EETimes) in the Innovator of the Year category in year 2005. Currently he is with Broadcom and works on issues related to next generation Bluetooth, milli-meter wave technologies, UWB, MIMO, Mesh Networking, Cognitive Radio, Viral communications and Cooperative networking. He also served as Adjunct Professor in Polytechnic University, Brooklyn teaching graduate course on Wireless Protocols. He is IEEE Standards Association voting member and Senior Member of IEEE and has served as Chair of many prestigious conferences and

has authored more than 60 conference and journal papers, and has filed more than 60 patents.

Special Session I

Special Session on Spectrum Aware Routing for Cognitive Radio Networks

Organizers

Jie Chen, UESTC, China
A.T. Hoang, Institute for Infocomm Research, Singapore

Abstract

Along with the advancement of cognitive radio, different types of network, such as infrastructure network and ad-hoc network, are introduced in the cognitive radio based wireless network architecture. To meet the requirements of multi-hop wireless communications, novel routing mechanism including algorithms and policies is needed for the emerging cognitive radio network. Due to the fact that two nodes within communication range in cognitive radio network may not have a common subset of available spectrum by which they can use to exchange data, the routing in such network becomes much more complicated and difficult than that of conventional wireless networks. Moreover, the available spectrum of each node may vary with time and spatial location, which makes the routing be highly dynamic in cognitive radio network. Then, the potential routing mechanism should be intelligent and robust to the varying wireless magnetic environment. In this special session, we target technical papers dealing with spectrum aware routing for cognitive radio networks.

Special Session II

Special Session on Commercialization of Cognitive Radio System for White Space Applications

Organizer

Kyutae Lim, Georgia Institute of Technology, USA

Abstract

In commercial wireless services under the current fixed spectrum policy, many spectrum segments, such as the cellular bands, are crowded by big user groups, while nearby spectrum is seldom used. Thus, researchers in wireless technology have been urged to create a new wireless communication system to use spectrum more efficiently. Cognitive Radio (CR) access technology has been proposed as a promising solution for improving the efficiency of spectrum usage by adopting the concept of dynamic spectrum resource management. The CR system is promising not only because it improves the efficiency of spectrum usage, but also because it promises improved connectivity and self-adaptability of the channel environment. The FCC has made the series of significant steps to enable CR, by proposing a rule making it possible for a secondary user to use the Digital TV spectrum, which called white space. Since then, various commercialization efforts with new paradigm are being made to be utilized in the white space. In this special session, state-of-the-art Cognitive Radio technologies for commercialization of white space applications are being presented and discussed by the invited speakers who are involving in the standardization.

TECHNICAL PROGRAM SCHEDULE – 1ST DAY

(THURSDAY, 15 MAY 2008)

TA1: Spectrum Sensing I

(Abstracts on Page 55)

16:00 – 18:00, Thursday 15 May 2008
Session Chair: Yonghong Zeng

Blind Spectrum Sensing for Cognitive Radio Based on Model Selection
Zayen Bassem (Eurecom), Nussbaum Dominique (Eurecom), Hayar Aawatif (Eurecom)

Parametric Density Estimation Using EM Algorithm for Collaborative Spectrum Sensing
Shun-Te Tseng (ECE, Purdue Univ.), Han-Ting Chiang (ECE, Purdue Univ.), James Lehnert (ECE, Purdue Univ.)

Sensing Optimization Considering Sensing Capability of Cognitive Terminal in Cognitive Radio System
Woongsup Lee (KAIST), Dong-Ho Cho (KAIST)

Double Threshold Energy Detection of Cooperative Spectrum Sensing in Cognitive Radio
Jiang Zhu (Huazhong University of Science and Technology), Zhengguang Xu (Huazhong University of Science and Technology), Furong Wang (Huazhong University of Science and Technology), Benxiong Huang (Huazhong University of Science and Technology), Bo Zhang (Huazhong University of Science and Technology)

Adaptive Sensing Threshold Control Based on Transmission Power in Cognitive Radio Systems
Hyun-Ho Choi (Samsung Advanced Institute of Technology), Kyunghun Jang (Samsung Advanced Institute of Technology), Yoonchae Cheong (Samsung Advanced Institute of Technology)

A Spread Signal Detection Algorithm based on the Second Order Statistics in Semi-Blind Contexts

Pierre Jallon (CEA)

TA2: Spectrum Policy

(Abstracts on Page 58)

16:00 – 18:00, Thursday 15 May 2008
Session Chair: Frederick Martin

Impact of Cognitive Radio on Future Management of Spectrum (Invited Paper)
Maziar Nekovee (BT Research)

Policy and Technology of Dynamic Spectrum Access in Korea (Invited Paper)
Chang-joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Cha-sik Leem (Software industry Bureau, Ministry of information and communication (MIC), Seoul, Korea), Sung-chul Kang (Radio Research Laboratory, Ministry of information and communication (MIC), Seoul, Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea)

Spectrum Survey in Singapore: Occupancy Measurements and Analyses (Invited Paper)
Md Islam (Institute for Infocomm Research), Geok Leng Tan (Info-communication Development Authority (IDA) of Singapore), Francois Chin (Institute for Infocomm Research), Bee Eng Toh (Info-communication Development Authority (IDA) of Singapore), Ying-Chang Liang (Institute for Infocomm Research), Cavin Wang (Info-communication Development Authority (IDA) of Singapore), Yoke Yong Lai (Info-communication Development Authority (IDA) of Singapore), Xianming Qing (Institute for Infocomm Research), Ser Wah Oh (Institute for Infocomm Research), Choo Leng Koh (Institute for Infocomm Research), William Toh (Info-communication Development Authority (IDA) of Singapore)

From Maxwell's Equations to Cognitive Radio (Invited Paper)
Jondral Friedrich K. (Universitat Karlsruhe (TH))

Making the Best out of Spectral Efficiency; Studies on The Introduction of Open-Spectrum Policy
Moonwon Lee (Electronics and Telecommunications Research Institute), Chasik Leem (Ministry of information and communication (MIC), Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Korea), Chang-joo Kim (Electronics and Telecommunications Research Institute), Hyunduk Kang (Electronics and Telecommunications Research Institute), Sungchul Kang (Ministry of information and communication (MIC), Korea)

Harmful Coexistence Between 802.15.4 and 802.11: A Measurement-based Study

Sofie Pollin (UC Berkeley / IMEC), Ian Tan (UC Berkeley), Bill Hodge (UC Berkeley), Carl Chun (UC Berkeley), Ahmad Bahai (UC Berkeley)

TA3: Cognitive Wireless Transmission I

(Abstracts on Page 61)

16:00 – 18:00, Thursday 15 May 2008
Session Chair: Rajarathnam Chandramouli

Power and Rate Control for Cognitive Radios: A Dynamic Programming Approach (Invited Paper)
Long Gao (Texas A&M University), Cui Shuguang (Texas A&M University)

Adaptive Subband Selection in OFDM-Based Cognitive Radios for Better System Coexistence
Pingzhou Tu (University of Wollongong), Xiaojing Huang (University of Wollongong), Eryk Dutkiewicz (University of Wollongong)

Optimal Transmission Strategy for Cognitive Radio Networks with Partial Channel State Information
Lan Zhang (National University of Singapore), Ying-Chang Liang (Institute of Infocomm Research), Yan Xin (National University of Singapore)

Orthogonal Beamforming Methodology in Cognitive Radio Networks
Yangsoo Kwon (Inha University), Jaehak Chung (Inha University), Hyeonsu Kim (Inha University), Jaeho Yoo (Inha University)

Cognitive Frequency Hopping
Rongxin Zhi (Beijing University of Posts and Telecommunications), LuYong Zhang (Beijing University of Posts and Telecommunications), Zheng Zhou (Beijing University of Posts and Telecommunications)

A Novel Power Control Approach Based on ε-Greedy Monte Carlo Method in Cognitive Radio System
Qinghai Xiao (Room 4-406 FIT Building, Tsinghua University,Beijing), Qunyi Gao (Tsinghua University), Yunzhou Li (Tsinghua University), Shidong Zhou (Tsinghua University), Jing Wang (Tsinghua University)

TECHNICAL PROGRAM SCHEDULE – 2ND DAY

(FRIDAY, 16 MAY 2008)

FM1: Capacity Limits

(Abstracts on Page 64)

11:20 – 13:00, Friday 16 May 2008
Session Chair: Rui Zhang

On the Secrecy Capacity of Fading Cognitive Wireless Networks (Invited Paper)
Anand Santhanakrishnan (Stevens Institute of Technology), Rajarathnam Chandramouli (Stevens Institute of Technology)

Limits on Cognitive Communications in the Wide-band Regime
Chulhan Lee (The University of Texas at Austin), Tie Liu (Texas A&M University), Ozgur Oyman (Intel Corporation), Sriram Vishwanath (The University of Texas at Austin)

Methods for Reducing Interference caused to Licensed Systems by Overlay-CSMA/CA Cognitive Radios
Athanassios Adamis (National Technical University of Athens - School of Electrical and Computer Engineering), Konstantinos Maliatsos (National Technical University of Athens - School of Electrical and Computer Engineering), Philip Constantinou (National Technical University of Athens - School of Electrical and Computer Engineering)

The Constraints Satisfied to Suppress the Interferences Caused by MB-OFDM UWB Based Cognitive Radio Systems
Cheng Yang (Wireless Network Lab,Beijing University of Posts and Communications), Zheng Zhou (Wireless Network Lab,Beijing University of Posts and Communications), Yabin Ye (Create-Net,Italy)

Uplink Distributed Binary Power Allocation for Cognitive Radio Networks
Majed Haddad (Eurecom Institute), Aawatif M. Hayar (Eurecom Institute), Geir E. Øien (Norwegian Univ. of Science and Technology), and Saad G. Kiani (Eurecom Institute)

FM2: Cognitive MAC/Scheduling

(Abstracts on Page 66)

11:20 – 13:00, Friday 16 May 2008
Session Chair: David Wong Tung Chong

State of the Art in Opportunistic Spectrum Access Medium Access Control Design (Invited Paper)
Przemyslaw Pawelczak (TU Delft), Sofie Pollin (UC Berkeley), Hoi-Sheung Wilson So (UC Berkeley), Ali Motamedi (Stanford University), Ahmad Bahai (Stanford University), R. Prasad (TU Delft), Ramin Hekmat (TU Delft)

Local Independent Control of Cognitive Radio Networks
Christian Doerr (University of Colorado), Dirk Grunwald (University of Colorado), Douglas Sicker (University of Colorado)

A Distributed Multi-channel Cognitive MAC Protocol for IEEE 802.11s Wireless Mesh Networks
Kaveh Ghaboosi (Centre for Wireless Communications, University of Oulu), Matti Latva-aho (Centre for Wireless Communications, University of Oulu), Yang Xiao (University of Alabama)

Scheduling Model for Cognitive Radio
Ping Zhu (University of Science and Technology of China), Jinglong Li (University of Science and Technology of China), Xufa Wang (University of Science and Technology of China)

Accumulative Interference Modeling for Cognitive Radios with Distributed Channel Access
Michael Timmers (IMEC - KULeuven), Sofie Pollin (IMEC - UC Berkeley), Antoine Dejonghe (IMEC), Ahmad Bahai (UC Berkeley - Stanford - NSC), Liesbet Van der Perre (IMEC - KULeuven), Francky Catthoor (IMEC - KULeuven)

FM3: Cognitive Radio Prototype

(Abstracts on Page 69)

11:20 – 13:00, Friday 16 May 2008
Session Chair: Wayne Stark

Cognitive Radio Prototyping (Invited Paper)
Prof. Dr. Peter Jung (Lehrstuhl fur Kommunikationstechnik), Alexander VIESSMANN (Lehrstuhl fur Kommunikationstechnik), Christoph SPIEGEL (Lehrstuhl fur Kommunikationstechnik), Admir BURNIC (Lehrstuhl fur Kommunikationstechnik), Zijian BAI (Lehrstuhl fur Kommunikationstechnik), Guido H. BRUCK (Lehrstuhl fur Kommunikationstechnik), Konstantin STATNIKOV (Lehrstuhl fur Kommunikationstechnik), Andreas WAADT (Lehrstuhl fur Kommunikationstechnik), Shangbo WANG (Lehrstuhl fur Kommunikationstechnik), Xavier POPON (Lehrstuhl fur Kommunikationstechnik), Rafael RODRIGUEZ VELILLA (Lehrstuhl fur Kommunikationstechnik), Harri SAARNISAARI (Lehrstuhl fur Kommunikationstechnik), Matthias ALLES (Lehrstuhl fur Kommunikationstechnik), Torben BRACK (Lehrstuhl fur Kommunikationstechnik), Frank KIENLE (Lehrstuhl fur Kommunikationstechnik), Friedbert BERENS (Lehrstuhl fur Kommunikationstechnik), Salvatore ROTOLO (Lehrstuhl fur Kommunikationstechnik), Fabio Mario SCALISE (Lehrstuhl fur Kommunikationstechnik), Norbert WEHN (Lehrstuhl fur Kommunikationstechnik)

Prototype of a Cognitive Radio System with Cooperative Sensing and Interference Alerting (Invited Paper)
Munehiro Matsui (NTT Network Innovation Laboratories, NTT Corporation), Kazunori Akabane (NTT Network Innovation Laboratories, NTT Corporation), Hiroyuki Shiba (NTT Network Innovation Laboratories, NTT Corporation), Kazuhiro Uehara (NTT Network Innovation Laboratories, NTT Corporation)

A Cross-layer Cognitive Radio Testbed for the Evaluation of Spectrum Sensing Receiver and Interference Analysis
Jongmin Park (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Kwan-woo Kim (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Taejoong Song (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Sang Min Lee (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Joonhoi Hur (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Kyutae Lim (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Joy Laskar (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology)

Cognitive Radio Software Testbed using Dual Optimization in Genetic Algorithm
Jaemoung Kim (Inha University), Sung Hwan Sohn (Inha University), Ning Han (Inha University), Guanbo Zheng (Inha University), Young Min Kim (Inha University), Joo Kwan Lee (Inha University)

A Cognitive UWB Testbed Employing Adaptive Pulse Generation
Nack-Hyun Choi (Inha University), JaeHo Hwang (Inha University), Guanbo Zheng (InhaUniversity), Ning Han (Inha University), Jae Moung Kim (Inha University)

FA1: Cognition & Reasoning

(Abstracts on Page 72)

14:00 – 16:00, Friday 16 May 2008
Session Chair: Chang-Joo Kim

Radio Environment Prediction for Cognitive Radio (Invited Paper)
Kazunori TAKEUCHI (KDDI R & D Laboratories Inc.), Shinichi NOMOTO (KDDI R & D Laboratories Inc.), Shoji Kaneko (KDDI R & D Laboratories Inc.)

Spectrum Sharing by Adaptive Transmit Power Control for Low Priority Systems and its Achievable Capacity
Hiromasa Fujii (NTT DoCoMo, Inc.), Hitoshi Yoshino (NTT DoCoMo, Inc)

Cognitive Decision Making Process Supervising the Radio Dynamic Reconfiguration
Nicholas Colson (France Telecom R&D), Apostolos Kountouris (France Telecom R&D), Armelle Wautier (SUPELEC), Lionel Husson (SUPELEC)

Predicting Radio Resource Availability in Cognitive Radio - an Experimental Examination
Shoji Kaneko (KDDI R&D Laboratories Inc.), Shinichi NOMOTO (KDDI R&D Laboratories Inc.), Tetsuro UEDA (KDDI R&D Laboratories Inc.), Shingo NOMURA (KDDI R&D Laboratories Inc.), Kazunori TAKEUCHI (KDDI R&D Laboratories Inc.)

An Estimation Algorithm of Channel State Transition Probabilities for Cognitive Radio Systems

Xin Long (Shanghai JiaoTong University), Xiaoying Gan (Shanghai JiaoTong University), Youyun Xu (Shanghai JiaoTong University), Jing Liu (Shanghai JiaoTong University), Meixia Tao (Shanghai JiaoTong University)

A Low Complexity Reconfigurable Filter Bank Architecture for Spectrum Sensing in Cognitive Radios
Mahesh Raveendranatha Panicker (Nanyang Technological University), Vinod Achutavarrier Prasad (Nanyang Technological University), Moy Christophe (SUPELEC), Jacques Palicot (SUPELEC)

FA2: Dynamic Spectrum Access

(Abstracts on Page 75)

14:00 – 16:00, Friday 16 May 2008
Session Chair: Ivan Cosovic

Dynamic Spectrum Assignment and Access Scenarios, System Architecture, Functional Architecture and Procedures for IEEE P1900.4 Management System (Invited Paper)
Stanislav Filin (NICT), Kentaro Ishizu (NICT), Homare Murakami (NICT), Hiroshi Harada (NICT), Go Miyamoto (NICT), Tran Nguyen (NICT), Shuzo Kato (NICT), Mikio Hasegawa (Tokyo University of Science)

A Bandwidth Pre-allocation Scheme for 'Beyond 3G' Multi-standard Base Station Using Measurement-based Admission Control
Teck Kiong Lee (Institute for Infocomm Research), Raymond Jayabal (Institute for Infocomm Research)

Dynamic Spectrum Access Techniques: TPC-resilient Initial Access in Open Spectrum Bands
Moonwon Lee (Electronics and Telecommunications Research Institute), Gwangzeen Ko (Electronics and Telecommunications Research Institute), Sunmin Lim (Electronics and Telecommunications Research Institute), Myungsun Song (Electronics and Telecommunications Research Institute), Changjoo Kim (Electronics and Telecommunications Research Institute)

Frequency Sharing Secondary System with Carrier Sense Assisted by Cellular System
Anwida Prompijit (Keio University), Takeo Fujii (The University of Electro-Communications), Chinnapat Sertthin (Keio University), Masao Nakagawa (Keio University)

Downlink Performance Analysis of Cognitive Radio based Cellular Relay Networks
Seungmo Kim (Information and Communications University), Wan Choi (Information and Communications University), Yonghoon Choi (Information and Communications University), Jongmin Lee (Information and Communications University), Youngnam Han (Information and Communications University), and Insun Lee (Samsung Advanced Institute of Technology)

An Access Technique Supporting Multimedia Traffic in Wireless Mesh and Ad-Hoc Networks
Chatu Lokuge (Industrial Research Limited), Alan Coulson (Industrial Research Limited)

FA3: Cognitive Wireless Transmission II

(Abstracts on Page 78)

14:00 – 16:00, Friday 16 May 2008
Session Chair: Joseph Evans

Pattern Based Encoding for Cognitive Communication
Ozgur Orcay (Istanbul Technical University), Berk Ustundag (Istanbul Technical University)

Radar spectrum opportunities for cognitive communications transmission
Lingfeng (Stephen) Wang (Centre for Communications Research, University of Bristol), Joe McGeehan (Centre for Communications Research, University of Bristol), Chris Williams (Fujitsu Laboratories of Europe), Angela Doufexi (Centre for Communications Research, University of Bristol)

Subband Adaptive Filtering for Efficient Spectrum Utilization in Cognitive Radios
Pingzhou Tu (University of Wollongong), Xiaojing Huang (University of Wollongong), Eryk Dutkiewicz (University of Wollongong)

Cognitive Pulse Shaping for M-ary Direct Sequence BPAM UWB System
Zhiquan Bai (School of Information Science and Engineering), Dongfeng Yuan (School of Information Science and Engineering, Shandong University), Haixia Zhang (School of Information Science and Engineering, Shandong University), Kyungsup Kwak (INHA UWB-ITRC, INHA University)

Pulse Based Adaptive Carrier Waveform Generation for Cognitive Radio Applications
Manju Mathew (Nanyang Technological University), Benjamin Premkumar (Nanyang Technological University), Lau Chiew Tong (Nanyang Technological University)

A Novel Nyquist Window for OFDM-based Cognitive Radio Systems
Ziyuan Yang (Shandong University), Dongfeng Yuan (School of Information Science and Engineering , Shandong University), Haixia Zhang (School of Information Science and Engineering , Shandong University), Zhiquan Bai (School of Information Science and Engineering , Shandong University), Kyungsup Kwak (INHA University Incheon)

FA4: Special Session: Spectrum-Aware Routing

(Abstracts on Page 81)

16:20 – 18:00, Friday 16 May 2008
Organisers: Jie Chen (UESTC, China) and Anh Tuan Hoang (Institute for Infocomm Research)
Session Chairs: Jie Chen & Anh Tuan Hoang

High Throughput Spectrum-aware Routing for Cognitive Radio Networks (Invited Paper)
Haitao Zheng (Univ. of California at Santa Barbara), Ashwin Sampath (Univ. of California at Santa Barbara), Lei Yang (Univ. of California at Santa Barbara), Lili Cao (Univ. of California at Santa Barbara), Ben Zhao (Univ. of California at Santa Barbara)

Spectrum-aware Location-based Routing in Cognitive UWB network
Fangmin Xu (Wireless Network Lab, Beijing University of Posts and Telecommunications), LuYong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunications), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunications), Yabin Ye (CREATE-NET,Italy)

Spectrum Aware Routing for Multi-Hop Cognitive Radio Networks with a Single Transceiver
Huisheng Ma (Institute of Science and Information, Xidian University), Lili Zheng (Institute of Science and Information, Xidian University), Xiao Ma (Institute of Science and Information, Xidian University), Yongjian luo (Xi'an Telecommunication institute)

Improving Capacity for Wireless Ad Hoc Communications Using Cognitive Routing
Yiming Liu (University of York), David Grace (University of York)

Cognitive routing models in UWB networks
Luca De Nardis (University of Rome La Sapienza), Maria-Gabriella Di Benedetto (University of Rome La Sapienza)

FA5: Spectrum Sharing

(Abstracts on Page 83)

16:20 – 18:00, Friday 16 May 2008
Session Chair: Maziar Nekovee

Misallocation-Averse Policy for Decentralized Resource Allocation in Spectrum Sharing Systems (Invited Paper)
Takefumi Yamada (NTT DoCoMo, Inc.), Ivan Cosovic (DoCoMo Communications Laboratories Europe GmbH), Koji Maeda (NTT DoCoMo, Inc.), Stefan Kaiser (DoCoMo Euro-Labs GmbH)

Interference Mitigation In Wireless Mesh Networks Through STDMA Wormhole Switching (Invited Paper)
Robert McTasney (University of Colorado at Boulder), Dirk Grunwald (University of Colorado at Boulder), Douglas Sicker (University of Colorado at Boulder)

Application of clustering structure in the hierarchical spectrum sharing network based on cognitive radio
Lei Gong (UESTC), Jie Chen (UESTC), Wanbin Tang (UESTC), Shaoqian Li (UESTC)

A Set Cover-Based Density Control Algorithm for Sensing Coverage Problems in Wireless Sensor Networks
Saran Jenjaturong (Chulalongkorn University), Chalermek Intanagonwiwat (Chulalongkorn University)

Plant-Floor Bluetooth Sensors with Adaptive Interference Management
Seetha Ramanjaneyulu B (CDAC), Gopinathan E (NIT Calicut)

FA6: TV White Space

(Abstracts on Page 85)

16:20 – 18:00, Friday 16 May 2008
Session Chair: Monisha Ghosh

Detection of White Spaces in a Cognitive Radio Architecture (Invited Paper)
Wayne Stark (University of Michigan), Pierre de Vries (University of Washington)

Spectrum Sensing Prototype For Sensing ATSC And Wireless Microphone Signals (Invited Paper)
Monisha Ghosh (Philips Research North America), Vasanth Gaddam (Philips Research North America), Gene Turkenich (Philips Research North America), Kiran Challapali (Philips Research North America)

White-Space Sensing Device for Detecting Vacant Channels in TV Bands (Invited Paper)
Ser Wah Oh (Institute for Infocomm Research), Syed Naveen A. A. (Institute for Infocomm Research), Yonghong Zeng (Institute for Infocomm Research), V. P. Kumar (Institute for Infocomm Research), T. P. C. Le (Institute for Infocomm Research), Karen J. M. Kua (Institute for Infocomm Research), Weiqiang Zhang (Institute for Infocomm Research)

The Spectral Efficiency analysis of the Spectrum Overlay technology of the TV band
Sangwon Kim (Electronics and Telecommunications Research Institute (ETRI)), Cha-sik Leem (Software industry Bureau, Ministry of information and communication (MIC), Seoul, Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea), Chang-joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Sung-chul Kang (Radio Research Laboratory, Ministry of information and communication (MIC), Seoul, Korea)

Conservative Protection Criteria for TV Broadcasting Services from IEEE 802.22 WRAN

Kimtho Po (Tokyo Institute of Technology), Jun ichi Takada (Tokyo Institute of Technology)

TECHNICAL PROGRAM SCHEDULE – 3RD DAY

(SATURDAY, 17 MAY 2008)

SM1: Spectrum Sensing II

(Abstracts on Page 87)

09:00 – 11:00, Saturday 17 May 2008
Session Chair: Yonghong Zeng

Distributed Autocorrelation-Based Sequential Detection of OFDM Signals in Cognitive Radios (Invited Paper)
Visa Koivunen (Helsinki Univ. of Technology (TKK)), sachin chaudhari (Helsinki University of Technology, Finland), H. Vincent Poor (Princeton University, USA)

A New Approach to Improve Signal Classification in Low SNR Environment in Spectrum *Sensing Hang Liu (Dalian University of Technology), Dan Yu (Dalian University of Technology), Xiangwei Kong (Dalian University of Technology)*

Nonparametric Cyclic Correlation Based Detection for Cognitive Radio Systems
Jarmo Lunden (Helsinki University of Technology, Finland), Saleem Kassam (University of Pennsylvania), Visa Koivunen (Helsinki University of Technology)

Statistical Test Based on Finding the Optimum Lag in Cyclic Autocorrelation for Detecting Free Bands in Cognitive Radios
Hao Feng (Institute of Information and Communication Engineering of Zhejiang University of China), Yanbo Wang (Institute of Information and Communication Engineering of Zhejiang University of China), Shiju Li (Institute of Information and Communication Engineering of Zhejiang University of China)

A Novel Active Spectrum Sensing Scheme for Cognitive MB-OFDM UWB Radio
Qi Liu (Wireless Network Lab, Beijing University of Posts and Telecommunications), Luyong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunications), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunications), Yabin Ye

Signal Detection Scheme for MB-OFDM through Fractional Sampling
Akio Kobori (Keio University), Yohei KATO (Keio University), Yukitoshi Sanada (Keio University)

SM2: Cognitive Networks & Security

(Abstracts on Page 90)

09:00 – 11:00, Saturday 17 May 2008
Session Chair: Anh Tuan Hoang

Exploiting Spatial Statistics of Primary and Secondary Users towards Improved Cognitive Radio Networks (Invited Paper)
Janne Riihijärvi (RWTH Aachen University), Petri Mähönen (RWTH Aachen University)

Adaptive Network Layer for Cognitive Radio Networks (Invited Paper)
Muthukumaran Pitchiamani (University of Kansas), Deepak Jeyaraman (University of Kansas), Joseph Evans (University of Kansas)

Security in Cognitive Radio Networks: Threats and Mitigation
Charles Clancy (Laboratory for Telecommunications Sciences), Nathan Goergen (University of Maryland)

Fuzzy-based Spectrum Handoff in Cognitive Radio Networks
Lorenza Giupponi (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)), Ana I. Pérez-Neira (Universitat Politècnica de Catalunya (UPC))

Security in Cognitive Radio Networks: The Required Evolution in Approaches to Wireless Network Security
Jack Burbank (The Johns Hopkins University Applied Physics Laboratory)

Architecture for Next-Generation Reconfigurable Wireless Networks using Cognitive Radio
Fangmin Xu (Wireless Network Lab, Beijing University of Posts and Telecommunications), LuYong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunication), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunication), Yabin Ye (CREATE-NET,Italy)

SM3: Special Session: Commercialization of Cognitive Radio System for White Space Applications

(Abstracts on Page 93)

09:00 – 11:00, Saturday 17 May 2008
Organiser: Kyutae Lim, George Tech
Session Chair: Kyutae Lim

Early Opportunities for Commercialization of TV Whitespace in the U. S. (Invited Paper)
Frederick Martin (Motorola, Inc.), Randy Ekl (Motorola, Inc.), Neiyer Correal (Motorola, Inc.), Robert O'Dea (Motorola, Inc.), Paul Gorday (Motorola, Inc.)

Cognitive Radio Networks: Enabling New Wireless Broadband Opportunities (Invited Paper)
Dave Cavalcanti (Philips Research North America), Monisha Ghosh (Philips Research North America)

Analysis of Aggregated Interference at DTV Receivers in TV Bands (Invited Paper)
Carlos Cordeiro (Intel Corporation), Sai Shankar Nandagopalan (Broadcom Corporation)

Design and Verification of IEEE 802.22 WRAN Physical Layer (Invited Paper)
Sung Hyun Hwang (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Jung Sun Um (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Myung Sun Song (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Chang-Joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Hyung Rae Park (School of Electronics, Telecommunication, and Computer Engineering, Hankuk Aviation University, Korea), Yun Hee Kim (School of Electronics and Information, Kyung Hee University, Korea)

A CR Platform for Applications in TV Whitespace Spectrum
Kihong Kim (Samsung Electro-Mechanics), Sungho Hwang (Samsung Electro-Mechanics), Junki Min (Samsung Electro-Mechanics), Seongsoo Lee (Samsung Electro-Mechanics), Kyungseok Kim (Chungbuk National University), Haksun Kim (Hanbat National University)

SM4: Cooperative Sensing

(Abstracts on Page 95)

11:20 – 13:00 Saturday 17 May 2008
Session Chair: Aarne Mämmelä

Contention-Aware Spectrum Sensing and Access Algorithm of Cognitive Network (Invited Paper)
Hu Gang (National University of Defense Technology), ZHANG Qian (HKUST), XU Ming (HKUST)

Sensing UMTS Bands Using Cyclostationary Features and Cooperation Between Opportunistic Terminal
Joaquim Bastos (Instituto de Telecomunicacoes), Paulo Marques (Escola Superior de Tecnologia - Instituto Politecnico de Castelo Branco), Atilio Gameiro (Instituto de Telecomunicacoes - Universidade de Aveiro)

Detection Fusion by Hierarchy Rule for Cognitive Radio
Wenzhong Wang (Beijing University of Post and Telecommunications), Weixia ZOU (Beijing University of Post and Telecommunications), Zheng ZHOU (Beijing University of Post and Telecommunications), Yabin Ye (Create-Net, Italy)

Sensor Pooling for Differential Sensing of Active and Idle Channels in Cognitive WPANs
Vojislav Misic (University of Manitoba, Winnipeg), Jelena Misic (University of Manitoba, Winnipeg, Canada)

Primary user detection in OFDM based MIMO Cognitive Radio
Rajarshi Mahapatra (Satyam Computer Services Ltd.), Vijaykumar Kuppusamy (Satyam Computer Services Ltd.)

SM5: Dynamic Spectrum Management

(Abstracts on Page 97)

11:20 – 13:00 Saturday 17 May 2008
Session Chair: Carlos Cordeiro

Resource Allocation for Cognitive Radios in Dynamic Spectrum Access Environment (Invited Paper)
Ekram Hossain (University of Manitoba), Dong Kim (Sungkyunkwan University (SKKU), Long Le (University of Waterloo)

Dynamic Spectrum Allocation with Second-Price Auctions: When Time is Money (Invited Paper)
*Anh Tuan Hoang (Institute for Infocomm Research, A*STAR, Singapore), Ying-Chang Liang (Institute for Infocomm Research, A*STAR, Singapore)*

Spectrum pool reassignment for wireless multi-hop relay systems
Ashish Pandharipande (Philips Research), Chin Keong Ho (Institute for Infocomm Research)

Aggregation Aware Spectrum Assignment in Cognitive Ad-hoc Networks
Dawei Chen (The Hong Kong University of Science and Technology), Qian Zhang (The Hong Kong University of Science and Technology), Weija Jia (City University of Hong Kong)

Game Theoretic Analysis of Joint Channel Selection and Power Allocation in cognitive radio networks
Hao He (UESTC), Jie Chen (UESTC), Shoufeng Deng (UESTC), Shaoqian Li (UESTC)

SM6: Physical Layer Design

(Abstracts on Page 100)

11:20 – 13:00 Saturday 17 May 2008
Session Chair: Kazunori TAKEUCHI and Md Islam Habibul

Performance Evaluation of Adaptive Non-contiguous MC-CDMA and Non-contiguous CI/MC-CDMA for Dynamic Spectrum Access
Zhiqiang Wu (Wright State University), Paul Ratazzi (Air Force Research Laboratory), Vasu Chakravarthy (Air Force Research Laboratory), Lang Hong (MRLets)

On the Impact of CFO for OFDM Systems with Un-equal Gain Diversity Schemes over Small-term Fading
Joy Chen (Department of Communication Engineering, Da Yeh University), Chin-Chung Yu (Department of Communication Engineering, Da Yeh University), You-Fu Chung (Department of Communication Engineering, Da Yeh University), Shi-Han Yan (Department of Communication Engineering, Da Yeh University)

Efficient scheme for DOA estimation of multipath clusters in WiMedia UWB systems
Rahim Leyman (Institute for Infocomm Research), Ashok Kumar Marath (Institute for Infocomm Research), Hari Krishna Garg (National University of Singapore)

Adaptive Two-Dimensional Channel Estimation Scheme for OFDM Systems
Chia-Horng Liu (Chunghwa Telecom. Co., Ltd./ Telecom. Lab.)

Phase Noise Analysis of PLL Based Frequency Synthesizers for Multi-Radio Mobile Terminals
Vaclav VALENTA (Universite Paris-Est, ESIEE, ESYCOM; Brno University of Technology), Geneviève BAUDOIN (Université Paris-Est,ESYCOM, ESIEE), Martine VILLEGAS (Université Paris-Est,ESYCOM, ESIEE)

ABSTRACTS

TA1: Spectrum Sensing I

Blind Spectrum Sensing for Cognitive Radio Based on Model Selection

Zayen Bassem (Eurecom), Nussbaum Dominique (Eurecom), Hayar Aawatif (Eurecom)

Cognitive radio devices will be able to seek and dynamically use frequency bands for network access. This will be done by autonomous detection of vacant sub-bands in the radio spectrum. In this paper, we propose a new method for blind detection of vacant sub-bands over the spectrum band. The proposed method exploits model selection tools like Akaike information criterion (AIC) and Akaike weights to sense holes in the spectrum band. Specifically, we assume that the noise of the radio spectrum band can still be adequately modeled using Gaussian distribution. We then compute and analyze Akaike weights in order to decide if the distribution of the received signal fits the noise distribution or not. Our theoretical results are validated using experimental measurements captured by Eurecom RF Agile Platform. Simulations show promising performance results of the proposed technique in terms of sensing vacant sub-bands in the spectrum.

Parametric Density Estimation Using EM Algorithm for Collaborative Spectrum Sensing

Shun-Te Tseng (ECE, Purdue Univ.), Han-Ting Chiang (ECE, Purdue Univ.), James Lehnert (ECE, Purdue Univ.)

Collaborative sensing of spectral occupancy can increase accuracy and relax the required sensitivity of individual sensing units. Collaborative sensing requires knowledge about the densities of collected sensing statistics to form the correct decision statistics for the optimum likelihood ratio test. In this paper, a parametric density estimation scheme using the expectation-maximization (EM) algorithm is proposed to estimate the parameters of densities that are drawn from a given family. When the log-likelihood function for the EM algorithm satisfies a certain condition, the maximization procedure is shown to require only a weighted sum of the collected sensing statistics. Numerical examples show that in various scenarios the proposed EM algorithm produces more accurate estimates than the sample average does.

Sensing Optimization Considering Sensing Capability of Cognitive Terminal in Cognitive Radio System

Woongsup Lee (KAIST), Dong-Ho Cho (KAIST)

Cognitive radio is a promising technology to overcome the insufficiency of available communication spectrums. In the cognitive radio system, many important issues exist. Spectrum sensing is one of the important issues, which has been studied throughout recently. In this paper, we propose a new distributed spectrum sensing scheme which considers the difference of sensing capabilities among cognitive terminals. By using our proposed scheme, we can effectively measure the sensing capability of a cognitive terminal and optimize the performance of the spectrum sensing by differentiating the

number of spectrum sensing that each cognitive terminal performs. Through performance analysis and numerical results, we show that our proposed scheme can achieve desired performance in view of the probability of false alarm and the probability of miss detection compared to a conventional scheme.

Double Threshold Energy Detection of Cooperative Spectrum Sensing in Cognitive Radio

Jiang Zhu (Huazhong University of Science and Technology), Zhengguang Xu (Huazhong University of Science and Technology), Furong Wang (Huazhong University of Science and Technology), Benxiong Huang (Huazhong University of Science and Technology), Bo Zhang (Huazhong University of Science and Technology)

Cognitive radio has become an effective theory to solve the inefficiency of the spectrum usage, and cooperative spectrum sensing among the secondary users to detect the primary user accurately is broadly studied before. In this paper, we employ a double threshold method in energy detector to perform spectrum sensing, while a fusion center in the cognitive radio network collects the local decisions and observational values of the secondary users, and then makes the final decision to determine whether the primary user is absence or not. Simulation results will show that the spectrum sensing performance in AWGN channels is improved significantly under the proposed scheme as opposed to the conventional method.

Adaptive Sensing Threshold Control Based on Transmission Power in Cognitive Radio Systems

Hyun-Ho Choi (Samsung Advanced Institute of Technology), Kyunghun Jang (Samsung Advanced Institute of Technology), Yoonchae Cheong (Samsung Advanced Institute of Technology)

Spectrum sensing is a key enabling technology for cognitive radio. Since there is a tradeoff between the probability of missed detection and the probability of false alarm according to a value of sensing threshold, it is very important to determine the sensing threshold suitable for cognitive radio environments. In this paper, we propose a novel method to determine the sensing threshold in the cognitive radio system, in which the secondary user (SU) first decides its transmission power for the communication and then decides the sensing threshold for the coexistence with the primary user (PU). For the coexistence, the SU controls its sensing threshold adaptively according to its transmission power in order to guarantee the minimum decodable SINR for the primary receiver. The analysis results show that the adaptively controlled sensing threshold decreases both the missed detection and the false alarm simultaneously and so enables both SU and PU to coexist in the same channel without interfering each other.

A Spread Signal Detection Algorithm based on the Second Order Statistics in Semi-Blind Contexts

Pierre Jallon (CEA)

In this contribution, we propose a spread signal detector based on the averaged-power of its autocorrelation function. A cost function that tests this property is build and some results are given on its estimation. We also explain how to use it to detect signals in SISO and SIMO cases. We conclude this paper with some numerical estimation of the proposed algorithm performances.

TA2: Spectrum Policy

Impact of Cognitive Radio on Future Management of Spectrum (Invited Paper)
Maziar Nekovee (BT Research)

Cognitive radio is a breakthrough technology which is expected to have a profound impact on the way radio spectrum will be accessed, managed and shared in the future. In this paper I examine some of the implications of cognitive radio for future management of spectrum. Both a near-term view involving the opportunistic spectrum access model and a longer-term view involving a self-regulating dynamic spectrum access model within a society of cognitive radios are discussed.

Policy and Technology of Dynamic Spectrum Access in Korea (Invited Paper)
Chang-joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Cha-sik Leem (Software industry Bureau, Ministry of information and communication (MIC), Seoul, Korea), Sung-chul Kang (Radio Research Laboratory, Ministry of information and communication (MIC), Seoul, Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea)

In this paper, we introduce spectrum policies and dynamic spectrum access technologies in Korea. In the past, Korea spectrum management was the command and control with exclusive usage rights and small portions of spectrum commons bands. With the development of the radio technologies, Recently, Korea government, MIC(ministry of information and communication), has been adopting new spectrum policies based on dynamic spectrum access technology such as LBT(Listen Before Talk) for RFID, UWB, and FACS(Flexible Access Common Spectrum) etc. MIC is also considering spectrum reallocation of digital dividend bands after DTV transition. New radio techniques such as cognitive radio and SDR will be applied to new services in this UHF band. MIC is trying to open the radio spectrum in an efficient way and adopt new technology into spectrum policy. Thus MIC is extending the open spectrum such as spectrum commons and spectrum liberalization bands.

Spectrum Survey in Singapore: Occupancy Measurements and Analyses (Invited Paper)
Md Islam (Institute for Infocomm Research), Geok Leng Tan (Info-communication Development Authority (IDA) of Singapore), Francois Chin (Institute for Infocomm Research), Bee Eng Toh (Info-communication Development Authority (IDA) of Singapore), Ying-Chang Liang (Institute for Infocomm Research), Cavin Wang (Info-communication Development Authority (IDA) of Singapore), Yoke Yong Lai (Info-communication Development Authority (IDA) of Singapore), Xianming Qing (Institute for Infocomm Research), Ser Wah Oh (Institute for Infocomm Research), Choo Leng Koh (Institute for Infocomm Research), William Toh (Info-communication Development Authority (IDA) of Singapore)

We study the 24-hour spectrum usage pattern in Singapore in the frequency bands ranging from 80 MHz to 5850 MHz. The objectives are to find how the scarce radio spectrum allocated to different services is utilized in Singapore and identify the bands

that could be accessed for future opportunistic use due to their low or no active utilization. The results from the spectrum measurements taken over 12 weekday periods reveal that a significant amount of spectrum in Singapore has very low occupancy all the time. The occupancy is quantified as the amount of spectrum detected above a certain received power threshold. The outcome of this study suggests that Singapore has a great potential for employing emerging spectrum sharing technology such as the cognitive radio technology to accommodate enormous demands for future wireless services. However, this study of spectrum survey is preliminary in its nature and future long term studies need to be performed to determine any potential secondary usage on those channels that have low or no active utilization.

From Maxwell's Equations to Cognitive Radio (Invited Paper)
Jondral Friedrich K. (Universitat Karlsruhe (TH))

Maxwell's equations that were published around 1865 caused Heinrich Hertz to prove the existence of electromagnetic waves. He succeeded in 1887/88. Around 1900, Marconi established the first long distance radio communication connections. During the following five decades, analog radio communication was brought to perfection. A big change in radio development was launched by Shannon with the publication of the sampling theorem in 1949. Together with the invention of the transistor and integrated circuits this led to the establishment of digital signal processing and, emerging from this, to the overwhelming success of digital cellular mobile radio. The demand for radio systems optimally adapted to different applications (personal, office, home, car, urban, rural environments) together with economic necessities resulted in the definition of a variety of standards (DECT, GSM, UMTS, IEEE 802.11x, Bluetooth, ZigBee, …), a development that called for SDRs. The next step in radio evolution will create devices that will help to make highest efficient use of the radio spectrum. In this scenario radios have to be aware of their location and to supervise their electromagnetic environment in order to be able to optimally adapt their transmission methods. This contribution tries to trace radio development from its origins to cognitive radio as well as to classify future developments.

Making the Best out of Spectral Efficiency; Studies on The Introduction of Open-Spectrum Policy
Moonwon Lee (Electronics and Telecommunications Research Institute), Chasik Leem (Ministry of information and communication (MIC), Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Korea), Chang-joo Kim (Electronics and Telecommunications Research Institute), Hyunduk Kang (Electronics and Telecommunications Research Institute), Sungchul Kang (Ministry of information and communication (MIC), Korea)

Open spectrum policy mostly deals with the shared-use of spectrum resources which again utilizes the orthogonality in different spectral domains - geography, space, power, frequency and time. Among these, temporal share of the spectrum, known as CR or cognitive radio technology, allows secondary licensees to opportunistically access the spectrum during the absence of the first. This paper provides the analysis on the

performance of CR implementations in IEEE 802.22 WRAN system, in terms of the spectrum utilization rate, along with simulation results. Also discussed are the regulatory issues in introducing open spectrum policies into the market, centered on the reuse of spectrum resources.

Harmful Coexistence Between 802.15.4 and 802.11: A Measurement-based Study
Sofie Pollin (UC Berkeley / IMEC), Ian Tan (UC Berkeley), Bill Hodge (UC Berkeley), Carl Chun (UC Berkeley), Ahmad Bahai (UC Berkeley)

Due to recent advances in wireless technology, a broad range of standards catering to a diverse set of users are currently emerging. Interoperability and coexistence between these heterogeneous networks are becoming key issues, and proper mitigation of these issues requires a good understanding of how and why heterogeneous networks may harm each other's performance. In this paper, we focus on the coexistence of 802.11 (wireless LAN) and 802.15.4 (sensor networks) in the ISM band. These networks have very different transmission characteristics that result in asymmetric interaction patterns. Consequently, many studies assume that the impact of 802.15.4 on 802.11 is negligible. In this paper, we examine this assumption in detail and show that, in many cases, 802.15.4 significantly impacts 802.11 performance. Even when 802.15.4 is executing a listen-before-send, which should theoretically prevent interference, a significant 802.11 performance degradation frequently occurs due to disparate slot sizes between the two protocols. This is one of the first papers studying the listen-before-send performance for heterogeneous networks with substantial measured data. The results raise important coexistence issues for 802.15.4 and 802.11 in particular, but even more so for dynamic spectrum sharing between heterogeneous devices in general.

TA3: Cognitive Wireless Transmission I

Power and Rate Control for Cognitive Radios: A Dynamic Programming Approach (Invited Paper)

Long Gao (Texas A&M University), Cui Shuguang (Texas A&M University)

In this paper, we investigate the power and rate control schemes for multiple cognitive radio (CR) links in the same neighborhood, which operate over multiple channels (frequency bands) in the presence of licensed primary radios (PRs). Specifically, by considering a practical delay in spectrum sensing, an efficient algorithm based on dynamic programming (DP) is proposed to maximize the average sum-rate of the CR links over a finite time horizon under the constraints on the CR-to-PR interference and the average transmit power for each CR link. In the proposed algorithm, the PR occupancy of each channel is modeled as a discrete-time Markov chain (DTMC). Based on such a model, a novel power and rate control strategy is derived, which is a function of the delayed spectrum sensing output, the instantaneous channel gains for the CR links, and the remaining power budgets for the CR transmitters. Simulation results show that the proposed algorithm leads to significant performance improvement over heuristic algorithms.

Adaptive Subband Selection in OFDM-Based Cognitive Radios for Better System Coexistence

Pingzhou Tu (University of Wollongong), Xiaojing Huang (University of Wollongong), Eryk Dutkiewicz (University of Wollongong)

In an environment of shared radio spectrum, multiple systems may interfere with each other and cause significant impacts on system coexistence. In this paper we propose an adaptive subband selection technique based on orthogonal frequency division multiplexing (OFDM) to avoid interference for better system coexistence when multiple systems are operating in the same unlicensed industrial, scientific and medical (ISM) bands. Under the assumption that the interference power level and the interfered frequency bands are identified at the receiver, interference thresholds, determined over both Gaussian and multipath fading channels, are applied to adaptively select the transmission subbands so that interference is avoided and the system coexistence issues are relaxed. To verify the effectiveness of the proposed adaptive subband selection method, the system bit error rates (BERs) under different interference levels are simulated and compared.

Optimal Transmission Strategy for Cognitive Radio Networks with Partial Channel State Information

Lan Zhang (National University of Singapore), Ying-Chang Liang (Institute of Infocomm Research), Yan Xin (National University of Singapore)

In this paper, we consider a spectrum sharing based cognitive radio (CR) network where the secondary user (SU) coexists with the primary user (PU) as long as the interference

power received by the PU is less than a acceptable threshold. Suppose that the SU's transmitter and receiver are equipped with multiple antennas and the PU's receiver are equipped with single receive antenna. We assume that the SU's channel state information (CSI) is known at the SU transmitter perfectly, however, due to less cooperation between the SU and the PU, only partial CSI between SU and PU is available at the SU transmitter. We seek to determine the optimal transmit signal covariance to maximize the transmission rate of the SU where the covariance is subject to the average interference power constraint of the PU as well as the transmit power constraint of the SU transmitter. Two iterative algorithms are proposed to solve these problems, and it is shown that the algorithms can converge to the optimal solution. Simulation results are provided to show the effectiveness of the algorithms.

Orthogonal Beamforming Methodology in Cognitive Radio Networks
Yangsoo Kwon (Inha University), Jaehak Chung (Inha University), Hyeonsu Kim (Inha University), Jaeho Yoo (Inha University)

Cognitive radio technique has been considered as a strong solution of frequency scarcity due to the limitation of frequency resource. In this paper, we propose an orthogonal beamforming methodology which enables cognitive radio systems to coexist with primary users' systems in the same spectrum and region with no interference to the primary users' systems. The orthogonal beams are obtained using Gram-Schmidt orthogonalization based on primary users' channel state information. In addition, to increase the sum-rate of the CR systems, the proposed scheme adopts an opportunistic beamforming method. Numerical results demonstrate that the proposed scheme does not cause interference to the primary users and provides higher sum-rate capacity than that of conventional CR systems.

Cognitive Frequency Hopping
Rongxin Zhi (Beijing University of Posts and Telecommunications), LuYong Zhang (Beijing University of Posts and Telecommunications), Zheng Zhou (Beijing University of Posts and Telecommunications)

To increase the scarcity of spectrum resources and enhance the anti –jamming performance of the system, a novel cognitive frequency hopping mechanism is proposed in the paper. It solves the problem that Adaptive Frequency Hopping can't distinguish between self-interference and interference from other wireless communication systems. The paper explains the mechanism of Cognitive Frequency Hopping and presents simulation results of Cognitive Frequency Hopping and Adaptive Frequency Hopping under same conditions.

A Novel Power Control Approach Based on ε-Greedy Monte Carlo Method in Cognitive Radio System

Qinghai Xiao (Room 4-406 FIT Building, Tsinghua University,Beijing), Qunyi Gao (Tsinghua University), Yunzhou Li (Tsinghua University), Shidong Zhou (Tsinghua University), Jing Wang (Tsinghua University)

In this paper, we consider a model of two-user channel with one primary user and one secondary user. Then we present a novel power control approach based on ε-greedy MC method to solve transmit-power control problem of the secondary user. Theoretical analysis and simulation results both show that the approach can not only optimize transmit-power control of the secondary user, but also be used to determine sensing error or interference temperature limit in cognitive-radio environment.

FM1: Capacity Limits

On the Secrecy Capacity of Fading Cognitive Wireless Networks (Invited Paper)
Anand Santhanakrishnan (Stevens Institute of Technology), Rajarathnam Chandramouli (Stevens Institute of Technology)

In this paper, we compute the primary exclusive region (PER) and the secrecy capacity at a primary receiver in a fading cognitive radio network. We consider Rayleigh fading and log-normal shadowing. We also study the effect of secrecy capacity on the PER. We show that log-normal shadowing and Rayleigh fading can degrade the PER by about 40% and the secrecy capacity by about 70%.

Limits on Cognitive Communications in the Wide-band Regime
Chulhan Lee (The University of Texas at Austin), Tie Liu (Texas A&M University), Ozgur Oyman (Intel Corporation), Sriram Vishwanath (The University of Texas at Austin)

This paper studies cognitive communication, where a cognitive transmit-receive pair utilizes an existing (occupied) wide-band spectrum for communication. The cognitive transmitter is assumed to have perfect knowledge on the signal levels of all the legitimate transmitters in the system and must cause negligible interference at all legitimate receivers. The goal of this research is to determine fundamental limits on communication in this setting. In particular, it is shown that communication with a minimum energy per bit arbitrarily close to that of a wide-band interference-free additive white Gaussian noise channel is possible using a pulse-position modulation scheme for the cognitive user in the wide-band limit.

Methods for Reducing Interference caused to Licensed Systems by Overlay-CSMA/CA Cognitive Radios
Athanassios Adamis (National Technical University of Athens - School of Electrical and Computer Engineering), Konstantinos Maliatsos (National Technical University of Athens - School of Electrical and Computer Engineering), Philip Constantinou (National Technical University of Athens - School of Electrical and Computer Engineering)

Cognitive Radios (CR) have recently appeared as a solution to the spectrum scarcity problem, caused by static licensing policies. CRs can utilize spectral opportunities when and where Licensed Systems (LS) remain idle, operating in an overlay mode under the major restriction of not causing harmful interference to them. In this Paper, first, we investigate the IEEE 802.11 DCF behavior in the overlay network, in terms of interference caused to the LS. The importance of the three way hand shake mechanism in the overlay scenario is discovered. Then, we introduce a 3rd state to the carrier sensing mechanism of the CR stations and we extend the DCF functionality by exploiting the new state. Two new protocols that utilize the new mechanism are proposed, both of which achieve substantial reduction in the interference caused to the LS. The second protocol also improves the performance of the CR Network in terms of throughput.

The Constraints Satisfied to Suppress the Interferences Caused by MB-OFDM UWB Based Cognitive Radio Systems

Cheng Yang (Wireless Network Lab,Beijing University of Posts and Communications), Zheng Zhou (Wireless Network Lab,Beijing University of Posts and Communications), Yabin Ye (Create-Net,Italy)

A Mathematical expression of side-band interferences caused by sub-carriers of multi-band (MB)-OFDM UWB based cognitive radio is derived. Based on this expression, the constraint relationship among transmitted symbols, which is satisfied to suppress the interferences, is obtained. Combined with this constraint, the design process of a type of LDPC-like modulation scheme is described. With modulation schemes of this type, the bit rate error (BER) performance of MB-OFDM UWB based cognitive radio systems is improved, and simultaneously, the side-band signals decrease more quickly. As a result, by the only measure of tuning off the sub-carriers at the corresponding position a deeper spectral notch can be generated. The interferences to other protected services are suppressed sufficiently and finally the coexistence is achieved between MB-OFDM UWB based cognitive radio system and other narrow band radio systems.

Uplink Distributed Binary Power Allocation for Cognitive Radio Networks

Majed Haddad (Eurecom Institute), Aawatif M. Hayar (Eurecom Institute), Geir E. Øien (Norwegian Univ. of Science and Technology), and Saad G. Kiani (Eurecom Institute)

Motivated by the desire for efficient spectral utilization, we present a novel algorithm for power allocation for sum rate maximization in cognitive radio context while preserving a guaranteed QoS for the primary network. To this effect, we propose a distributed cognitive radio coordination that maximizes the Cognitive Radio Network (CRN) sum rate while minimizing the interference to the primary users (PU). Our goal is to realize spectrum sharing by optimally allocating secondary users (SU) transmit powers in order to maximize the total SU throughput under interference and noise impairments. Both theoretical and simulation results under realistic wireless network settings are shown to exhibit interesting features in term of CRN deployment while maintaining QoS for the primary system.

FM2: Cognitive MAC/Scheduling

State of the Art in Opportunistic Spectrum Access Medium Access Control Design (Invited Paper)

Przemyslaw Pawelczak (TU Delft), Sofie Pollin (UC Berkeley), Hoi-Sheung Wilson So (UC Berkeley), Ali Motamedi (Stanford University), Ahmad Bahai (Stanford University), R. Prasad (TU Delft), Ramin Hekmat (TU Delft)

Opportunistic Spectrum Access (OSA) allows unlicensed secondary networks to share licensed spectrum in space and time, but only when licensed users are not using the spectrum. Thus this novel spectrum management technique started drawing the attention of researchers recently. Although many interesting approaches have been proposed, most techniques are early proposals that often only cover a subset of the problems related to OSA. In this paper, we give an extensive overview of Medium Access Control design challenges specific to OSA, while discussing the main approaches proposed so far in the literature. We give an extensive survey of protocols proposed and discuss which features are not explored yet and which one need to be looked at more carefully.

Local Independent Control of Cognitive Radio Networks

Christian Doerr (University of Colorado), Dirk Grunwald (University of Colorado), Douglas Sicker (University of Colorado)

Many different algorithms for managing cognitive radio networks have been proposed. While these algorithms have applied the whole range from centrally managed to distributed control schemes, a common feature of previous work is the reliance on explicit communication to exchange and negotiate configuration information. This paper describes a new class of cognitive radio control algorithms employing local independent control based upon swarming behavior found in nature. We examine the feasibility of such local independent control in a testbed implementation of the algorithm, configuring and dynamically adapting a cognitive radio network. We find that approach is suited to coordinate a cognitive radio network based on passive observation of its environment only and may coordinate with other control algorithms deployed in heterogeneous secondary user networks.

A Distributed Multi-channel Cognitive MAC Protocol for IEEE 802.11s Wireless Mesh Networks

Kaveh Ghaboosi (Centre for Wireless Communications, University of Oulu), Matti Latva-aho (Centre for Wireless Communications, University of Oulu), Yang Xiao (University of Alabama)

In this paper, we propose a novel distributed frequency agile medium access control (MAC) extension to the IEEE 802.11s amendment for the next generation wireless mesh networks (WMNs). The proposed scheme has complete backward compatibility with the legacy IEEE 802.11 and the emerging 802.11s while, it is perfectly capable of multi-channel deployment of available frequency opportunities in order to coordinate

concurrent multiple data transmissions. The root concept of the proposed enhancement is mainly based on the deployment of well-known ISM frequency bands, where the existing 802.11-based wireless equipments nowadays operate, as the common control channel in order to establish concurrent data transmissions. Here, we apply the aforementioned key concept to the IEEE 802.11s common channel framework (CCF) to attain two important goals: on one hand, the proposed scheme improves the channel utilization and capacity using the concept of cognitive radio and on the other hand, using the same concept it leads to lower access delay due to smarter decision making procedures exploited for link layer connection establishment. Through extensive simulations, which also take into account primary user (PU) appearance in non-ISM frequency opportunities, performance of the proposed medium access control (MAC) enhancement is evaluated showing its remarkable efficiency and better wireless medium access management.

Scheduling Model for Cognitive Radio

Ping Zhu (University of Science and Technology of China), Jinglong Li (University of Science and Technology of China), Xufa Wang (University of Science and Technology of China)

The priority queue model divides CR(cognitive radio) system users into primary user and secondary user. The primary user has preemptive priority over secondary user, while the same priority level users are FIFO served. This paper models the CR system based on scheduling technology. The secondary users are further divided into different priority levels. A hybrid priority dynamic policy, which indicates primary user‘s preemptive priority and secondary user‘s nonpreemptive priority, is developed to reduce spectrum switch overhead during spectrum leasing process. Theoretical analyzing shows that hybrid priority reduces the spectrum switch overhead and the hybrid priority improvement is a non-negative mono-increasing function of priority level. Based on the proposed policy, CR scheduling model is built and CR scheduling rule is provided and proved. Experimental comparison between CR scheduling and priority queue shows that CR scheduling gets a smaller weighted staying time sum than priority queue and the improvement increases as system becomes more congested.

Accumulative Interference Modeling for Cognitive Radios with Distributed Channel Access

Michael Timmers (IMEC - KULeuven), Sofie Pollin (IMEC - UC Berkeley), Antoine Dejonghe (IMEC), Ahmad Bahai (UC Berkeley - Stanford - NSC), Liesbet Van der Perre (IMEC - KULeuven), Francky Catthoor (IMEC - KULeuven)

A Cognitive Radio (CR) network should be able to sense its environment and adapt its communication to utilize unused licensed spectrum without interfering with incumbents. Properly modeling the expected interference from the CR network is therefore very important in the definition of coexistence rules to efficiently protect the incumbents. In this paper we model the accumulative interference generated from a large-scale CR network and investigate how this affects the sensing requirements of the CRs to meet an interference constraint. More specifically, our model considers the

impact of discrete topology and the impact of the distributed channel access scheme. As an instantiation of our model, we consider a CR network based on the IEEE 802.11 standard. We show that the interference generated is large, since collisions cannot be avoided.

FM3: Cognitive Radio Prototype

Cognitive Radio Prototyping (Invited Paper)

Prof. Dr. Peter Jung (Lehrstuhl fur Kommunikationstechnik), Alexander VIESSMANN (Lehrstuhl fur Kommunikationstechnik), Christoph SPIEGEL (Lehrstuhl fur Kommunikationstechnik), Admir BURNIC (Lehrstuhl fur Kommunikationstechnik), Zijian BAI (Lehrstuhl fur Kommunikationstechnik), Guido H. BRUCK (Lehrstuhl fur Kommunikationstechnik), Konstantin STATNIKOV (Lehrstuhl fur Kommunikationstechnik), Andreas WAADT (Lehrstuhl fur Kommunikationstechnik), Shangbo WANG (Lehrstuhl fur Kommunikationstechnik), Xavier POPON (Lehrstuhl fur Kommunikationstechnik), Rafael RODRIGUEZ VELILLA (Lehrstuhl fur Kommunikationstechnik), Harri SAARNISAARI (Lehrstuhl fur Kommunikationstechnik), Matthias ALLES (Lehrstuhl fur Kommunikationstechnik), Torben BRACK (Lehrstuhl fur Kommunikationstechnik), Frank KIENLE (Lehrstuhl fur Kommunikationstechnik), Friedbert BERENS (Lehrstuhl fur Kommunikationstechnik), Salvatore ROTOLO (Lehrstuhl fur Kommunikationstechnik), Fabio Mario SCALISE (Lehrstuhl fur Kommunikationstechnik), Norbert WEHN (Lehrstuhl fur Kommunikationstechnik)

Future wireless systems have been evolving toward a broadband and open architecture for efficient multi-service operation, which will have a great impact on the terminal and infrastructure component design methodology for supporting multiple radio schemes. Cooperation in wireless networks, requiring cognitive radio implementations, will facilitate a new dimension in the evolution of multimedia communications. The growing price pressure requires ever increasing high levels of integration efficiency, of flexibility and of future proofness at the same time, setting out in the digital baseband domain. In this communication, the authors will illustrate a platform based prototyping process, setting out from the paradigm developed in the IST-27960 STREP URANUS (UNIVERSAL RADIO-LINK PLATFORM FOR EFFICIENT USER-CENTRIC ACCESS). URANUS investigates the design of a universal radio link platform able to be incorporated in any existing proprietary and standardized wireless system in a seamless way, to ease the introduction of future personalized communications and reconfigurable air interfaces.

Prototype of a Cognitive Radio System with Cooperative Sensing and Interference Alerting (Invited Paper)

Munehiro Matsui (NTT Network Innovation Laboratories, NTT Corporation), Kazunori Akabane (NTT Network Innovation Laboratories, NTT Corporation), Hiroyuki Shiba (NTT Network Innovation Laboratories, NTT Corporation), Kazuhiro Uehara (NTT Network Innovation Laboratories, NTT Corporation)

Cognitive radio systems provide dynamic spectrum access, which is expected to improve frequency use efficiency. These systems need a sensing function to avoid interference from other radio stations. However, it is impossible to completely avoid interference because no perfect sensing function has been developed. To solve this problem, we propose using a new cognitive radio system with three main functions: cooperative sensing, interference alerting, and frequency management. We developed and evaluated a prototype of the system and found that the system is effective.

A Cross-layer Cognitive Radio Testbed for the Evaluation of Spectrum Sensing Receiver and Interference Analysis

Jongmin Park (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Kwan-woo Kim (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Taejoong Song (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Sang Min Lee (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Joonhoi Hur (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Kyutae Lim (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology), Joy Laskar (Georgia Electronic Design Center (GEDC), Georgia Institute of Technology)

Cognitive radio (CR) technology has been proposed as a promising solution for maximizing the utilization of already-crowded spectrum resources. As new algorithms, circuits and systems are developed for CR technology, it is essential to have a reconfigurable testbed system for their verification. A multi-standard, fully software driven, cross-layer CR testbed has been developed to support thorough testing of CR system and custom designed integrated circuits (ICs). This paper presents details of cross-layer CR testbed and three demonstrations of testbed usage; (a) cognitive radio system concept demonstration, (b) multi-resolution spectrum sensing (MRSS) receiver IC evaluation, (c) interference analysis for UWB coexistence with WiMax. With this reconfigurable testbed, a new idea can be easily verified, demonstrated and extended to further research.

Cognitive Radio Software Testbed using Dual Optimization in Genetic Algorithm

Jaemoung Kim (Inha University), Sung Hwan Sohn (Inha University), Ning Han (Inha University), Guanbo Zheng (Inha University), Young Min Kim (Inha University), Joo Kwan Lee (Inha University)

Cognitive Radio is considered as a potential solution to improve spectrum utilization via opportunistic spectrum sharing. In this paper, we present a software testbed which is developed to implement the cognitive radio system. The basic functions of cognitive radio are explored and implemented, including spectrum sensing and dynamic spectrum management. The testbed is able to verify the overall performance of cognitive radio technology. Furthermore, it provides an important system model to verify the effectiveness of the new algorithms in future study. The simulation on the testbed demonstrates that primary and secondary users can coexist. This is able to convince regulatory authorities as well as primary users to enable the implementation of cognitive radio technology.

A Cognitive UWB Testbed Employing Adaptive Pulse Generation

Nack-Hyun Choi (Inha University), JaeHo Hwang (Inha University), Guanbo Zheng (InhaUniversity), Ning Han (Inha University), Jae Moung Kim (Inha University)

Ultra Wideband (UWB) is a promising underlying method for coexistence among different systems. However, the performance may not be as good as expected due to the changing spectrum environment. Thus, cognitive UWB radio is proposed by taking the advantage of cognition, which enables the radio to learn the spectrum environment by

itself. In this paper, we explore a cognitive UWB testbed in physical layer, including cognitive pulse generator, stream view and performance evaluation. In order to protect the potential narrowband systems, the specific mask and channel information are utilized to adapt the system parameters with the help of pulse mask code and pulse generation block. Simulation results show that the proposed testbed is capable to generate the adaptive pulse that suitable for different spectrum environment.

FA1: Cognition & Reasoning

Radio Environment Prediction for Cognitive Radio (Invited Paper)
Kazunori TAKEUCHI (KDDI R & D Laboratories Inc.), Shinichi NOMOTO (KDDI R & D Laboratories Inc.), Shoji Kaneko (KDDI R & D Laboratories Inc.)

The authors introduce the new index of the wireless resources as "availability of wireless transmission capability" than the existing and the well known the radio intensity like Signal/Noise ratio, BER or re-transmission ratio. This index enables us to compare the wireless resources between the heterogeneous wireless media. Moreover, it can applicable to the unlicensed band like Wi-Fi where many wireless nodes act themselves as the primary system in the same area. The verification of the possibility and applicability of the radio environment prediction are shown using field data in various points. Based on the results of the verification, the possibility and the accuracy to predict the wireless media capacity according to the radio environment parameter are shown. The result is independent of locations of the field. Furthermore, the advantage of the prediction in comparison with the approach without prediction is shown from the viewpoint of statistics.

Spectrum Sharing by Adaptive Transmit Power Control for Low Priority Systems and its Achievable Capacity
Hiromasa Fujii (NTT DoCoMo, Inc.), Hitoshi Yoshino (NTT DoCoMo, Inc)

A spectrum sharing method is proposed for the systems which share the same frequency band or adjacent bands with different priorities. The proposed method adaptively controls transmission power according to information offered by high-priority system receivers. We give theoretical capacities achieved by low-priority systems when the proposed method and a conventional method (constant transmit power) are applied. Numerical results confirm that the proposed method attains 1.5-2 times larger capacity than the conventional method.

Cognitive Decision Making Process Supervising the Radio Dynamic Reconfiguration
Nicholas Colson (France Telecom R&D), Apostolos Kountouris (France Telecom R&D), Armelle Wautier (SUPELEC), Lionel Husson (SUPELEC)

Cognitive radio is a technological concept pushing for the introduction of intelligent radio operation going beyond system adaptation and reconfiguration on the basis of simple criteria and rules. Insofar, a rather limited amount of work has been published on the cognitive mechanisms that should be embedded into the communicating equipments to achieve such an intelligent behavior. Towards filling this gap, this paper presents an innovative optimization algorithm driving the decision making process supervising the cognitive radio reconfiguration. This cognitive algorithm, called RALFE for "Reason And Learn From Experience", presents interesting features since it allows to perform autonomous decision making with regard to multiple, possibly conflicting,

operational objectives in the face of an uncertain environment. The proposed approach is illustrated for a case of cognitive waveform design.

Predicting Radio Resource Availability in Cognitive Radio - an Experimental Examination

Shoji Kaneko (KDDI R&D Laboratories Inc.), Shinichi NOMOTO (KDDI R&D Laboratories Inc.), Tetsuro UEDA (KDDI R&D Laboratories Inc.), Shingo NOMURA (KDDI R&D Laboratories Inc.), Kazunori TAKEUCHI (KDDI R&D Laboratories Inc.)

This paper presents a method for predicting radio resource availability in cognitive radio. In this paper, unlike a primary / secondary model, cognitive radio is defined as wireless communication technology in which each node communicates via an optimal wireless system based on recognition of radio resource availability in heterogeneous wireless communication systems. Therefore, it is important to be able to recognize such radio resource availability accurately. However, a cognitive radio node is unable to recognize the subsequent radio resource availability at the time of selecting the optimal wireless system. The authors focus on the prediction of radio resource availability to resolve the above issue. In this paper, the authors focus on IEEE802.11 [1] and radio channel occupation time, which is calculated from packet length and the transmission rate, is used as radio resource availability. From the results of the examination, it would seem feasible that the auto-correlation coefficient (or partial auto-correlation coefficient) could be utilized as information on the reliability of the prediction value when an auto-regression model (AR model) is used for the prediction. Furthermore, by comparing n-step-ahead prediction for a time series calculated for a 1-second interval and 1-step-ahead prediction for a time series calculated for an n-second interval, it is shown that the accuracy of the prediction in both cases is almost identical when the information volume to calculate a prediction expression is the same. Therefore, either prediction approach can be selected depending on the cognitive radio system.

An Estimation Algorithm of Channel State Transition Probabilities for Cognitive Radio Systems

Xin Long (Shanghai JiaoTong University), Xiaoying Gan (Shanghai JiaoTong University), Youyun Xu (Shanghai JiaoTong University), Jing Liu (Shanghai JiaoTong University), Meixia Tao (Shanghai JiaoTong University)

In this paper, an estimation algorithm of channel state transition probabilities in Markov channel model for cognitive radio systems is proposed. The framework of POMDP is adopted to solve the problem of channel selection. Maximum likelihood method is used to estimate the channel state transition probabilities, which is crucial to POMDP. Central Limit Theorem is introduced to get the relationship between the precision, sample times and the channel state transition probability values. The simulation results show the reliability of the estimation results.

A Low Complexity Reconfigurable Filter Bank Architecture for Spectrum Sensing in Cognitive Radios

Mahesh Raveendranatha Panicker (Nanyang Technological University), Vinod Achutavarrier Prasad (Nanyang Technological University), Moy Christophe (SUPELEC), Jacques Palicot (SUPELEC)

The primary task in any cognitive radio (CR) network is to dynamically sense the radio spectrum so as to reliably determine portion(s) of the frequency band that may be used for communication link(s). Recently spectrum sensing for CRs based on filter banks have been addressed in literature. It was suggested that using filter banks for spectrum sensing would offer new opportunities of communicating at no extra cost. This means the reuse of sensing filter banks for transmission purpose also. But there was no consideration on the complexity issues associated with filter banks for CR. In this paper, we present a new low complexity reconfigurable filter bank architecture for multi-standard CR. The proposed filter bank is compared with other approaches and comparison results show that the proposed architecture is ideally suited for the CR systems.

FA2: Dynamic Spectrum Access

Dynamic Spectrum Assignment and Access Scenarios, System Architecture, Functional Architecture and Procedures for IEEE P1900.4 Management System (Invited Paper)

Stanislav Filin (NICT), Kentaro Ishizu (NICT), Homare Murakami (NICT), Hiroshi Harada (NICT), Go Miyamoto (NICT), Tran Nguyen (NICT), Shuzo Kato (NICT), Mikio Hasegawa (Tokyo University of Science)

Implementing dynamic spectrum assignment and access technologies in heterogeneous wireless networks may lead to considerable improvement in spectrum usage. For this purpose, management system shall be added on top of existing heterogeneous wireless system. IEEE P1900.4 working group has been developing such management system. In this paper, we propose different scenarios for IEEE P1900.4 dynamic spectrum assignment and access use cases. We propose enhancements to IEEE P1900.4 system architecture. Also, we propose functional architecture for IEEE P1900.4 management system. Finally, we propose generic procedures to implement proposed scenarios using proposed system architecture.

A Bandwidth Pre-allocation Scheme for 'Beyond 3G' Multi-standard Base Station Using Measurement-based Admission Control

Teck Kiong Lee (Institute for Infocomm Research), Raymond Jayabal (Institute for Infocomm Research)

In a totally reconfigurable network, base stations can be viewed as amorphous entities that are dynamically configured to an optimal combination of radio access technologies based upon the time-varying user density and QoS requirements of the application traffic that they present or will present to it. In such a network, admission control is typically useful in providing load balancing and hotspot mitigation functionalities. In this paper, we propose to use a Measurement-based Admission Control (MBAC) to manage the allocation of baseband processing bandwidth in a multi-standard base station. Using realistic Voice and Video traffic traces, we highlight the MBAC performance in both homogeneous and heterogeneous traffic environments.

Dynamic Spectrum Access Techniques: TPC-resilient Initial Access in Open Spectrum Bands

Moonwon Lee (Electronics and Telecommunications Research Institute), Gwangzeen Ko (Electronics and Telecommunications Research Institute), Sunmin Lim (Electronics and Telecommunications Research Institute), Myungsun Song (Electronics and Telecommunications Research Institute), Changjoo Kim (Electronics and Telecommunications Research Institute)

Fast frequency channel saturation is one of big challenges in open spectrum bands. System designers may easily come up with TPC (Transmission Power Control) applied to the down-streams of a network, to increase the cell reuse factor, but this scheme alone is likely to encounter initial access issues where beacons are not either receivable or

decodable inside the network's maximum transmission range. Such problems can be handled in two major approaches; First, relaying beacons in a distributed manner to statistically sweep out hidden areas. Second, explicit demand of beacons from a connecting device. The latter is called active scan (or sending probes) and can guarantee successful connections to the network if, and only if, appropriate mechanisms are provided to avoid interference to neighboring networks. In that context, we will explore a wide span of DSA (Dynamic Spectrum Access) techniques and introduce a system, called DPA (Discrete Probe Access)-OFDMA, where probe frames are transmitted with orthogonality maintained in the power and code domain. A group of cognitive techniques to boost the efficiency of active scans will be presented too.

Frequency Sharing Secondary System with Carrier Sense Assisted by Cellular System
Anwida Prompijit (Keio University), Takeo Fujii (The University of Electro-Communications), Chinnapat Sertthin (Keio University), Masao Nakagawa (Keio University)

Cognitive radio offers a tempting solution to increase the spectrum usage efficiency by proposing opportunistic usage of frequency bands among licensed users and secondary users. This paper focuses on mitigating the interference that may occur when the secondary user is unaware of the primary user's active period; known as hidden terminal problem. Path attenuation and shadowing effect are also considered. In this paper, in order to enhance the sensing capability of the cognitive radio system, we propose a cognitive radio system with the combination of active and passive awareness types, by the collaboration of carrier sense and cellular system. Here, we present the simulation results of the system with microwave relay as a primary user and ad hoc cognitive radio terminals as a secondary user. Three different cases are evaluated; the conventional system, the system with carrier sense, and the system with carrier sense assisted by cellular system.

Downlink Performance Analysis of Cognitive Radio based Cellular Relay Networks
Seungmo Kim (Information and Communications University), Wan Choi (Information and Communications University), Yonghoon Choi (Information and Communications University), Jongmin Lee (Information and Communications University), Youngnam Han (Information and Communications University), and Insun Lee (Samsung Advanced Institute of Technology)

In this paper, we propose two operating scenarios of employing cognitive radio to downlink of relay networks. The first scenario uses ISM band while the second scenario exploits opportunity of channel use at UHF spectrum. The capacity gain over conventional relay is investigated in terms of the normalized system capacity. We first statistically model the spectrum usage pattern in those bands and derive the achievable data rate and outage probability in order to analyze performance gain in the view of practical system establishment. Then, we define system capacity by normalizing the effect of bandwidth so that a fair comparison of performance is accomplished. Through our analysis and simulations, it is shown that the proposed scenarios are able to achieve significant gains over a conventional cellular relay system in terms of the normalized

system capacity. As a result, relay combined with cognitive radio can be considered as a viable solution to get higher downlink capacity.

An Access Technique Supporting Multimedia Traffic in Wireless Mesh and Ad-Hoc Networks

Chatu Lokuge (Industrial Research Limited), Alan Coulson (Industrial Research Limited)

This paper examines the end-to-end (source to destination) link performance characteristics when a novel Media Access Control (MAC) protocol is used to support multimedia traffic in ad-hoc and mesh networks. The performance analysis was performed by a Monte Carlo simulator, the accuracy of which was verified by an analytical Markov model analysis. An overlaid two cell structure was considered for the Monte Carlo simulation where the terminals can be mobile within this environment. The system model includes Rice fading, log-normal shadowing and distance dependent pathloss. The system model also considers preferential channel access based on the capture effect. The MAC protocol proposed in this study indicated satisfactory performance characteristics in the presence of multimedia traffic. The results further shows performance benefits of mesh networks over ad-hoc systems. The paper also shows how network density affects the network performance.

FA3: Cognitive Wireless Transmission II

Pattern Based Encoding for Cognitive Communication

Ozgur Orcay (Istanbul Technical University), Berk Ustundag (Istanbul Technical University)

A new encoding technique based on construction of communication signals with respect to optimal perceptual pattern sensitivity of the cognitive receivers is proposed here. Communication signals are directly generated and adapted according to medium properties without a modulator stage. Receivers recognize signal patterns from a chosen frequency band. These patterns are matched to respecting data sequence within a glossary to recover the information. Our purpose is increasing the bandwidth efficiency via manageable Signal to Noise Ratio. Error free recoverability of the information encoded and carried by multiple pattern combinations in a noisy communication channel is the key factor for this purpose. A pattern based encoding and neural network based decoding technique is used in this study. It is shown that if the predefined communication patterns are appropriately chosen then the transmitted information by multiple sources can be decoded by the receivers in the same time interval, frequency band and location.

Radar spectrum opportunities for cognitive communications transmission

Lingfeng (Stephen) Wang (Centre for Communications Research, University of Bristol), Joe McGeehan (Centre for Communications Research, University of Bristol), Chris Williams (Fujitsu Laboratories of Europe), Angela Doufexi (Centre for Communications Research, University of Bristol)

In relation to opportunistic access to radar spectrum, the impact of the radar on a communication system is investigated in this paper. This paper illustrates that by exploring the spatial and temporal opportunities in the radar spectrum and therefore improving the tolerance level to radar interference, a substantial increase on the throughput of a communication system is possible. Results are presented regarding the impact of swept radars on a WiMAX system. The results show the impact of SIR (Received WiMAX signal to received radar signal ratio), radar antenna radiation patterns and rotation period estimation on the feasibility of radar spectrum access.

Subband Adaptive Filtering for Efficient Spectrum Utilization in Cognitive Radios

Pingzhou Tu (University of Wollongong), Xiaojing Huang (University of Wollongong), Eryk Dutkiewicz (University of Wollongong)

Efficient spectrum utilization can be achieved in several ways, one of which is a better spectrum access. In this paper we propose a subband adaptive filtering method for effective spectrum access and dynamic spectrum sharing in cognitive radios (CR). Based on an interleaved spread spectrum orthogonal frequency division multiplexing (ISS-OFDM) multiple subband transmission signal and subband adaptive filtering technique, some interfered subbands of the transmission signal are filtered and dropped off. The other subbands without interference or with interference less than a predetermined

threshold are used for information transmission. The flexibility of the adaptively selecting transmission subbands provides users with the ability to fill in spectrum holes with appropriate number of subbands. Consequently, the spectrum utilization efficiency is improved. We simulate the system bit error rate (BER) performances and demonstrate the improvement on spectrum utilization efficiency by using this subband adaptive filtering method, when different numbers of subbands are used for information transmission.

Cognitive Pulse Shaping for M-ary Direct Sequence BPAM UWB System
Zhiquan Bai (School of Information Science and Engineering), Dongfeng Yuan (School of Information Science and Engineering, Shandong University), Haixia Zhang (School of Information Science and Engineering, Shandong University), Kyungsup Kwak (INHA UWB-ITRC, INHA University)

In this paper, based on a new pulse waveform design algorithm of ultra wideband pulse [5], we employ this algorithm into a cognitive M-ary code selected direct sequence bipolar pulse amplitude modulation ultra wideband communication system. This M-ary DS-UWB system can utilize the cognitive waveform to realize the high performance and high data rate cognitive communication. The bit error rate performance of the M-ary system with the novel pulse waveform is presented in this paper. The proposed scheme can be realized under different situations with lower interference to primary wireless devices and acceptable system complexity. Further more, through the pulse design, we can also generate some good candidate waveform sets which satisfy the FCC regulation.

Pulse Based Adaptive Carrier Waveform Generation for Cognitive Radio Applications
Manju Mathew (Nanyang Technological University), Benjamin Premkumar (Nanyang Technological University), Lau Chiew Tong (Nanyang Technological University)

A radio that is capable of adapting to its environment by continuous learning and observation is called Cognitive Radio (CR). The developments in DSP and IC technologies catalyze the evolution of this 4G wireless system which makes reliable communication and efficient usage of radio spectrum. To make cognitive radio a reality changes in physical, MAC and network layers of the conventional system is essentially required. The major physical layer issues include wideband front end, intelligent spectrum sensing and adaptive transmission scheme. In our work, we address the adaptive transmission issue and propose a new method. The method is for generating a time domain pulse in Radio Frequency (RF) range with the required frequency response. The proposed method is compared with existing potential candidates for cognitive radio transmission.

A Novel Nyquist Window for OFDM-based Cognitive Radio Systems
Ziyuan Yang (Shandong University), Dongfeng Yuan (School of Information Science and Engineering , Shandong University), Haixia Zhang (School of Information Science and

Engineering , Shandong University), Zhiquan Bai (School of Information Science and Engineering , Shandong University), Kyungsup Kwak (INHA University Incheon)

Cognitive radio (CR) is one of the important paradigms proposed by FCC for improving the spectrum utilization. To make agile spectrum resources allocation between the primary users (PUs) and the secondary users (SUs), Orthogonal Frequency Division Multiplexing (OFDM) has been taken as one of the potential modulation candidates in the physical layer in CR. This paper presents a mathematical model for measuring the interference in the windowed OFDM systems. Additionally, we introduce a novel optimized Nyquist window approach to decrease the out-of-band radiation, such that the interference to the adjacent non-orthogonal users can be avoided. Both theoretical analysis and numerical results show the performance enhancement of the proposed scheme.

FA4: Special Session: Spectrum-Aware Routing

High Throughput Spectrum-aware Routing for Cognitive Radio Networks (Invited Paper)

Haitao Zheng (Univ. of California at Santa Barbara), Ashwin Sampath (Univ. of California at Santa Barbara), Lei Yang (Univ. of California at Santa Barbara), Lili Cao (Univ. of California at Santa Barbara), Ben Zhao (Univ. of California at Santa Barbara)

Dynamic spectrum networks enable fast deployment of new wireless technologies by effectively utilizing allocated yet unused wireless spectrum. By sensing and utilizing available wireless channels, cognitive radio devices can provide high throughput, low latency communication. Existing schemes for channel assignment suffer drawbacks in throughput and reachability in the presence of location-dependent channel availability. We propose SPEctrum-Aware Routing Protocol (SPEAR), a robust and efficient distributed channel assignment and routing protocol for dynamic spectrum networks based on two principles: integrated spectrum and route discovery for robust multi-hop path formation, and distributed path reservations to minimize inter- and intra-flow interference. Through simulations and testbed measurements, we show that SPEAR establishes robust paths in diverse spectrum conditions and provides near-optimal throughput and end-to-end packet delivery latency. SPEAR performs extremely fast flow setup and teardowns, and can maintain interference-free flows in the presence of variance in channel availability.

Spectrum-aware Location-based Routing in Cognitive UWB network

Fangmin Xu (Wireless Network Lab, Beijing University of Posts and Telecommunications), LuYong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunications), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunications), Yabin Ye (CREATE-NET,Italy)

Cognitive Ultra-Wideband (UWB) network is the UWB network with the ability of sensing spectrum, detecting the available spectrum holes in primary system, and communicate in the detected spectrum holes. Based on the precise position capability of UWB technology and the spectrum sensing information, local clusters are constructed by neighbor nodes which operated in the same spectrum channel, and the entire network is interconnected by the clusters through bridge gateway nodes. Furthermore, a spectrum-aware routing scheme is provided for clustered cognitive UWB network, which including the process of routing discovery and repairing. The unique feature of this routing scheme is its ability of intelligent adaptation to the change of network and available spectrum resource. Simulation proved the performance of spectrum-aware routing in dynamic spectrum environment is better than traditional routing scheme with fixed spectrum allocation.

Spectrum Aware Routing for Multi-Hop Cognitive Radio Networks with a Single Transceiver

Huisheng Ma (Institute of Science and Information, Xidian University), Lili Zheng (Institute of Science and Information, Xidian University), Xiao Ma (Institute of Science and Information, Xidian University), Yongjian luo (Xi'an Telecommunication institute)

In multi-hop single transceiver Cognitive Radio networks (MSCRN), routing becomes of great challenge when IEEE 802.11 DCF is used as the MAC protocol. Routing should not base on common control channel because it is not ensured that common control channel can be obtained by each node. In this paper, we propose a spectrum aware on-demand routing which doesn't base on control channel. A channel assignment algorithm aimed at improving link utilization is derived based on delay-analysis. The overhead and gain by switching is balanced in this algorithm. For deafness problem caused by switching can result in significant performance degradation, we give the constraints to avoid the appearance of this problem in channel assignment process. We stress that our approach can be easily implemented for the using of standard IEEE 802.11DCF. Results of simulation show that, our approach can well fit MSCRN and improve the network throughput comparing to the same network scenario without cognitive ability.

Improving Capacity for Wireless Ad Hoc Communications Using Cognitive Routing

Yiming Liu (University of York), David Grace (University of York)

This paper is devoted to the development of cognitive routing techniques for a wireless ad hoc network in order to improve scalability and effectively the supportable capacity. Different routing strategies are examined and a novel capacity-based routing strategy is emphasized. Its capacity performance is evaluated using conventional shortest path routing as a benchmark. It shows the proposed capacity-based routing strategy can reduce the overall interference level in the system by shifting traffic to the edge of the network. It can also support more originating capacity compared with the shortest path routing strategy where each node has a maximum capacity constraint.

Cognitive routing models in UWB networks

Luca De Nardis (University of Rome La Sapienza), Maria-Gabriella Di Benedetto (University of Rome La Sapienza)

This paper investigates the effect of introducing cognitive mechanisms in the routing module of a wireless network. A routing cost function that incorporates measurements of both internal network status and instantaneous behavior of external world is described. The proposed cost function is analyzed by simulation in the framework of IEEE 802.15.4a-like low data rate and low cost networks for mixed indoor/outdoor communications. The analysis focuses on the impact of MUI modeling on network performance. Results indicate that MUI-awareness, as provided by the proposed cognitive cost function, may improve network performance in terms of network lifetime. Based on this analysis, a mechanism for learning from previous routing decisions and adapting the routing cost function to MUI conditions is introduced.

FA5: Spectrum Sharing

Misallocation-Averse Policy for Decentralized Resource Allocation in Spectrum Sharing Systems (Invited Paper)

Takefumi Yamada (NTT DoCoMo, Inc.), Ivan Cosovic (DoCoMo Communications Laboratories Europe GmbH), Koji Maeda (NTT DoCoMo, Inc.), Stefan Kaiser (DoCoMo Euro-Labs GmbH)

It is becoming increasingly difficult to satisfy the growing demands on spectrum with the conventional policy of fixed spectrum allocation. To overcome this problem, flexible and dynamic spectrum sharing methods that can significantly improve utilization of the spectrum have gained increasing interest recently. In this paper, resource allocation in decentralized spectrum sharing systems applying the existing policy rule referred to as "inequality-averse policy" is focused on. The problem related to the impact of inaccurate estimation of future traffic demands on the performance of such systems is addressed. To alleviate the problem, a novel policy termed misallocation-averse policy, which introduces adjusting factors and is resistant to such estimation errors, is proposed. The effectiveness of the proposed policy rule is verified through computer simulations.

Interference Mitigation In Wireless Mesh Networks Through STDMA Wormhole Switching (Invited Paper)

Robert McTasney (University of Colorado at Boulder), Dirk Grunwald (University of Colorado at Boulder), Douglas Sicker (University of Colorado at Boulder)

Cognitive radio networks offer the promise of adaptively allocating resources on the fly. In this paper, we describe an interference mitigation technique that relies on intelligent resource allocation across a mesh network. In previous work, we presented a method for improving the performance of Wireless Mesh Networks (WMN) through the use of multichannel wormhole switching (see [1] and [2]). An approximate 800-fold improvement was shown in latency with slightly lower path setup times over carrier sense multiple access collision avoidance (CSMA/CA) 802.11-based wireless mesh networks. In addition, the goodput in terms of percent frames successfully received was improved from 40 to 80 percent. In this paper we present the results of applying interference-based conflict graphs and space-time division multiple access (STMDA) scheduling at the cost of increasing the latency to improve the goodput from 80 percent to close to 100 percent.

Application of clustering structure in the hierarchical spectrum sharing network based on cognitive radio

Lei Gong (UESTC), Jie Chen (UESTC), Wanbin Tang (UESTC), Shaoqian Li (UESTC)

This paper firstly analyzes the impact which clustering and non-clustering structure is on sensing spectrum expenditure. Furthermore, the reason that clustering structure is adopted in hierarchical spectrum sharing network is also illustrated by numerical simulation. Secondly, a clustering algorithm, which can reduce detection expenditure, is proposed based on the similarity of the spectrum in such architecture. Additionally,

clustering stability based on this algorithm is explored. Theoretical analysis and simulation result indicates that clustering stability is ensured only if threshold K is chosen appropriately.

A Set Cover-Based Density Control Algorithm for Sensing Coverage Problems in Wireless Sensor Networks

Saran Jenjaturong (Chulalongkorn University), Chalermek Intanagonwiwat (Chulalongkorn University)

Wireless sensor networks consist of a large number of sensor nodes with limited power and resource. To prolong network lifetime, the energy consumption must be somehow reduced. In this paper, we propose a localized density control algorithm for energy savings. The goals are to maintain a minimal number of active sensor nodes and to reduce radio traffic intensity while conserving the sensing coverage of the network. Our localized algorithm is based on a greedy solution of a weighted set-cover problem. Each node locally computes whether to sleep or to stay active. Given that the local decision might worsen the sensing coverage, we also introduce a voting scheme for selecting active nodes to assure that a node can sleep if and only if its sensing area is completely covered by its active neighbors. We have implemented our localized algorithm and voting scheme on Tiny OS and evaluated on TOSSIM. The result indicates that our algorithm is efficient and viable for practical use.

Plant-Floor Bluetooth Sensors with Adaptive Interference Management

Seetha Ramanjaneyulu B (CDAC), Gopinathan E (NIT Calicut)

When different wireless devices of various technologies that operate in the same frequency band, are deployed at sensor and controller levels of plant floors, it is possible for them to cause interference to each other's transmissions. In general Bluetooth or ZigBee like low power solutions are used at sensor levels and high-power solutions like Wi-Fi are used at controller levels. In these contexts, the low-power sensor transmissions suffer more. It results in lesser throughput and higher latencies of sensor data. Because of these increased latencies, sensors may fail to satisfy their real-time data transfer obligations. In such cases, techniques like selective retransmissions of high-priority data and hop-sequence rearrangement of frequency-hopping devices would be useful to manage the interference problems of sensor level devices. Three such methods are proposed in this work. By employing these methods, wireless sensors that operate in interfered environments can be made to support real-time data transfers that are possible with wired sensor buses like Controller Area Network (CAN).

FA6: TV White Space

Detection of White Spaces in a Cognitive Radio Architecture (Invited Paper)
Wayne Stark (University of Michigan), Pierre de Vries (University of Washington)

In this paper we consider the use of UHF spectrum that is not allocated to digital TV transmission for unlicensed wireless devices. We model the propagation conditions and calculate the threshold necessary for detection that results in a small probability of creating interference to TV receivers. The threshold depends on the number of wireless devices. We calculated the reduction in threshold possible when multiple devices cooperate to detect the presence of a TV signal.

Spectrum Sensing Prototype For Sensing ATSC And Wireless Microphone Signals (Invited Paper)
Monisha Ghosh (Philips Research North America), Vasanth Gaddam (Philips Research North America), Gene Turkenich (Philips Research North America), Kiran Challapali (Philips Research North America)

Spectrum sensing is the key enabler for dynamic spectrum access in the television (TV) bands as it can allow secondary networks to reuse spectrum without causing harmful interference to primary users. In this paper we describe a sensing prototype that has been developed to demonstrate robust sensing of TV signals as well as wireless microphone signals in the laboratory and field. We will present the algorithms as well as simulation, lab and field test results that validate the prototype's capability to identify these signals down to a level of -116 dBm.

White-Space Sensing Device for Detecting Vacant Channels in TV Bands (Invited Paper)
Ser Wah Oh (Institute for Infocomm Research), Syed Naveen A. A. (Institute for Infocomm Research), Yonghong Zeng (Institute for Infocomm Research), V. P. Kumar (Institute for Infocomm Research), T. P. C. Le (Institute for Infocomm Research), Karen J. M. Kua (Institute for Infocomm Research), Weiqiang Zhang (Institute for Infocomm Research)

Measurements performed at several locations clearly show that frequency spectrum is under-utilized. Cognitive radio is a strong candidate to ensure better spectrum utilization by providing access in an opportunistic manner. Simulations performed on the algorithm that we proposed show promising results in sensing vacant channels in TV Bands. Here we present the work, which implements the algorithm on a real-time prototype, and measure its sensing performance in actual environments. Results show that our algorithm is robust under realistic conditions. This confirmation will give much needed confidence in the capability of cognitive radio systems to detect the operation of primary users and protect their use of spectrum.

The Spectral Efficiency analysis of the Spectrum Overlay technology of the TV band
Sangwon Kim (Electronics and Telecommunications Research Institute (ETRI)), Cha-sik Leem (Software industry Bureau, Ministry of information and communication (MIC), Seoul, Korea), Jaiyong Lee (Department of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea), Chang-joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Sung-chul Kang (Radio Research Laboratory, Ministry of information and communication (MIC), Seoul, Korea)

In this paper, we discuss the spectral efficiency and coverage efficiency of WRAN(Wireless Regional Area Network) system in TV bands which are under standardization at the IEEE 802.22 WG. Instead of spectrum underlay technologies which have been used conventionally, spectrum overlay technology model will be the subject of analysis and simulations in this paper. The research results revealed that the increase of spectral reuse distance (guard distance) negatively affects the spectral and coverage efficiency. In WRAN system that uses spectrum overlay technologies and where the Tx power of TV stations and WRAN BSs are constant, decrease in both of the spectral efficiency and the coverage efficiency were observed in counter-proportion to the increasing guard distance at the size of given area(about 400 to 800 km).

Conservative Protection Criteria for TV Broadcasting Services from IEEE 802.22 WRAN
Kimtho Po (Tokyo Institute of Technology), Jun ichi Takada (Tokyo Institute of Technology)

IEEE 802.22 Wireless Regional Area Network (IEEE 802.22 WRAN) is considered for operating in the television (TV) bands without causing harmful interference to the primary users i.e. TV users. To tackle this problem, the authors propose an alternative method for calculating the protection distances between the WRAN devices and the TV protection contour where the WRAN devices are not permitted to radiate their powers since they may cause harmful interference to the TV users. The proposed calculation is similar to the one used for the impact study of ultra wideband (UWB) devices to the existing services in Japan. In this approach, the protection distances are calculated based on the interference-to-noise ratio (INR) at the TV receiver with respect to two deterministic propagation models. One is free space model and the other is spherical earth model. In addition, the comparison of the propagation loss and the protection distances between the proposed study and the conventional one are also presented.

SM1: Spectrum Sensing II

Distributed Autocorrelation-Based Sequential Detection of OFDM Signals in Cognitive Radios (Invited Paper)

Visa Koivunen (Helsinki Univ. of Technology (TKK)), sachin chaudhari (Helsinki University of Technology, Finland), H. Vincent Poor (Princeton University, USA)

This paper addresses the problem of collaborative spectrum sensing using sequential detection (SD) in cognitive radios. The goal of sequential processing is to reduce the delay and amount of data needed in identifying underutilized spectrum. Each secondary user (SU) employs a simple and computationally efficient autocorrelation-based detector for Orthogonal Frequency Division Multiplexing (OFDM) signals of the primary user (PU). The decision statistics from individual detectors are combined in a fusion center that may be a separate node or one of the secondary users. The statistical properties of the decision statistics are established. The performance of the scheme is studied by theory and simulations. A comparison of the SD scheme with the Neyman-Pearson Fixed Sample Size (FSS) test for the same false alarm and missed detection probabilities is also carried out.

A New Approach to Improve Signal Classification in Low SNR Environment in Spectrum *Sensing*

Hang Liu (Dalian University of Technology), Dan Yu (Dalian University of Technology), Xiangwei Kong (Dalian University of Technology)

The performance of Cognitive radio is sensitive to the accuracy of signal classification. The proposed method can increase the accuracy of existing methods on the certain degree at SNR=0 dB and below. In simulation, we classify five types of signals which are AM, BPSK, FSK, MSK and QPSK. The experiments show that above 99.9% received signals are correctly classified at SNR= -12 dB and above.

Nonparametric Cyclic Correlation Based Detection for Cognitive Radio Systems

Jarmo Lunden (Helsinki University of Technology, Finland), Saleem Kassam (University of Pennsylvania), Visa Koivunen (Helsinki University of Technology)

In this paper a nonparametric cyclic correlation estimator based on complex generalization of sign function is proposed. Theoretical justification for detecting cyclostationary signals is provided. Asymptotic distribution of the estimator under null hypothesis is established. Constant false alarm rate (CFAR) tests based on estimated sign cyclic correlation are derived for single-user and collaborative spectrum sensing. Simulation experiments comparing the proposed method with cyclostationarity based spectrum sensing methods employing the classical cyclic correlation estimator are performed. Nonparametric statistics provide additional robustness when noise statistics are non-Gaussian or not fully known. Simulations demonstrate the reliable performance and robustness of the proposed nonparametric spectrum sensing method in both Gaussian and non-Gaussian noise environments.

Statistical Test Based on Finding the Optimum Lag in Cyclic Autocorrelation for Detecting Free Bands in Cognitive Radios

Hao Feng (Institute of Information and Communication Engineering of Zhejiang University of China), Yanbo Wang (Institute of Information and Communication Engineering of Zhejiang University of China), Shiju Li (Institute of Information and Communication Engineering of Zhejiang University of China)

Cognitive radios sense the radio spectrum in order to find free bands for transmission. In this paper, a novel method is proposed for detecting free bands by exploiting a statistical test based on finding the optimum lag in cyclic autocorrelation of primary user signals within the framework of cyclostationarity theory. This approach has a satisfying detecting performance under low SNR conditions and is computational efficient. Meanwhile, due to signals' cyclostationarity, the method also has a good anti-interference property which can be utilized to detect the primary user signals in the presence of interference. Finally, simulations are performed to verify those properties of the proposed method.

A Novel Active Spectrum Sensing Scheme for Cognitive MB-OFDM UWB Radio

Qi Liu (Wireless Network Lab, Beijing University of Posts and Telecommunications), Luyong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunications), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunications), Yabin Ye

Spectrum awareness is the key technique for Cognitive Radio (CR). A special spectrum sensing scheme is necessary for Cognitive UWB radio (CUWB) because of its lower radio power and ultra wide bandwidth. Although CUWB transmitter and receiver could respectively detect the spectrum holes, they couldn't communicate with each other probably if they are out of the communication range or there isn't common usable spectrum segment for them. No sensing technique deals with these problems properly. In this paper a novel active spectrum sensing scheme for cognitive MB-OFDM UWB radio is presented to settle the above problems. The scheme takes full advantage of UWB and finds usable channels directly for CUWB transmitter and receiver through sending beacon signals and acknowledgement signals. This active spectrum sensing scheme is totally different from existing sensing methods and has its own advantages.

Signal Detection Scheme for MB-OFDM through Fractional Sampling

Akio Kobori (Keio University), Yohei KATO (Keio University), Yukitoshi Sanada (Keio University)

Currently, detect and avoid (DAA) techniques of UWB have been paid large attention because it has been regulated in Japan and Europe. In this paper, a novel signal detection scheme for coexistence of UWB and the 4th generation mobile communication systems is proposed. The proposed scheme makes use of multipath through fractional sampling. The probabilities of false detection and false alarm with fractional sampling in a MB-OFDM receiver are investigated. The numerical results show that the proposed scheme with fractional sampling improves the probability of false detection by about 10

times as compared to conventional schemes. The numerical results also prove that the DFT size can be reduced without increasing the probability of false detection.

SM2: Cognitive Networks & Security

Exploiting Spatial Statistics of Primary and Secondary Users towards Improved Cognitive Radio Networks (Invited Paper)
Janne Riihijärvi (RWTH Aachen University), Petri Mähönen (RWTH Aachen University)

We show how locations of primary and secondary users of spectrum can be characterized quantitatively using modern spatial statistics techniques. We argue that several interesting practical engineering applications can be based on these methods. In order to demonstrate the developed techniques, we will apply those to real-world data in particularly TV-transmitter locations in the USA. The spatial statistic techniques have a natural use in the analysis of Dynamic Spectrum Access (DSA) opportunities. We expect that the presented methods have strong potential to be used not only for theoretical work, but also as foundations for concrete protocols and algorithms for improved cognitive radios.

Adaptive Network Layer for Cognitive Radio Networks (Invited Paper)
Muthukumaran Pitchiamani (University of Kansas), Deepak Jeyaraman (University of Kansas), Joseph Evans (University of Kansas)

Cognitive radios present unique challenges in the design of a suitable network layer for networks formed by these devices. The network layer must be robust, adaptive and dynamic to meet these challenges by allowing the cognitive functionality further into the protocol stack. In this paper we outline a model for dynamic adaptation using two candidate classes of network layers and describe its various components. We evaluate aspects of the feasibility of the approach using simulation based studies.

Security in Cognitive Radio Networks: Threats and Mitigation
Charles Clancy (Laboratory for Telecommunications Sciences), Nathan Goergen (University of Maryland)

This paper describes a new class of attacks specific to cognitive radio networks. Wireless devices that can learn from their environment can also be taught things by malicious elements of their environment. By putting artificial intelligence in charge of wireless network devices, we are allowing unanticipated, emergent behavior, fitting a perhaps distorted or manipulated level of optimality. The state space for a cognitive radio is made up of a variety of learned beliefs and current sensor inputs. By manipulating radio sensor inputs, an adversary can affect the beliefs of a radio, and consequently its behavior. In this paper we focus primarily on PHY-layer issues, describing several classes of attacks and giving specific examples for dynamic spectrum access and adaptive radio scenarios. These attacks demonstrate the capabilities of an attacker who can manipulate the spectral environment when a radio is learning. The most powerful of which is a self-propagating AI virus that could interactively teach radios to become malicious. We then describe some approaches for mitigating the effectiveness of these attacks by instilling some level of "common sense" into radio systems, and requiring

learned beliefs to expire and be relearned. Lastly we provide a road-map for extending these ideas to higher layers in the network stack.

Fuzzy-based Spectrum Handoff in Cognitive Radio Networks
Lorenza Giupponi (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)), Ana I. Pérez-Neira (Universitat Politècnica de Catalunya (UPC))

This paper focuses on spectrum handoffs in a cognitive radio network where secondary (unlisenced) users (i.e. cognitive radios) opportunistically use frequency channels as long as the aggregate interference caused at the primary (licensed) users does not exceed a certain threshold. When harmful interference is caused to a primary user, or when the quality of service perceived by a secondary user is not satisfactory, the secondary user has to initiate a spectrum handoff to quickly vacate the channel it is occupying. The proposal in this paper is a fuzzy-based approach able to make effective spectrum handoff decisions in a context characterized by uncertain, incomplete and heterogeneous information.

Security in Cognitive Radio Networks: The Required Evolution in Approaches to Wireless Network Security
Jack Burbank (The Johns Hopkins University Applied Physics Laboratory)

This paper discusses the topic of wireless security in cognitive radio networks, delineating the key challenges in this area. With the ever-increasing scarcity of spectrum, cognitive radios are expected to become an increasingly important part of the overall wireless networking landscape. However, there is an important technical area that has received little attention to date in the cognitive radio paradigm: wireless security. The cognitive radio paradigm introduces entirely new classes of security threats and challenges, and providing strong security may prove to be the most difficult aspect of making cognitive radio a long-term commercially-viable concept. This paper delineates the key challenges in providing security in cognitive networks, discusses the current security posture of the emerging IEEE 802.22 cognitive radio standard, and identifies potential vulnerabilities along with potential mitigation approaches.

Architecture for Next-Generation Reconfigurable Wireless Networks using Cognitive Radio
Fangmin Xu (Wireless Network Lab, Beijing University of Posts and Telecommunications), LuYong Zhang (Wireless Network Lab, Beijing University of Posts and Telecommunication), Zheng Zhou (Wireless Network Lab, Beijing University of Posts and Telecommunication), Yabin Ye (CREATE-NET,Italy)

The next generation of wireless networks, as envisioned by recent advances in cognitive radio (CR) technologies, will be intelligently adjust their configuration to changes in the communication environment. Reconfigurability is set to be an important facet in the evolving world of mobile and wireless communications, through which technologies

such as cognitive radio are greatly facilitated. In next generation of reconfigurable wireless networks, various wireless access networks coexist in the same frequency band using cognitive radio and internetworking using IP Multimedia Subsystem(IMS). This paper therefore discusses the introduction of a system architecture that incorporates cognitive radio and IMS. The architecture takes the emerging 3GPP system and Wimax system as an example, and focuses on the issue of common signaling, resource management and security.

SM3: Special Session: Commercialization of Cognitive Radio System for White Space Applications

Early Opportunities for Commercialization of TV Whitespace in the U. S. (Invited Paper)

Frederick Martin (Motorola, Inc.), Randy Ekl (Motorola, Inc.), Neiyer Correal (Motorola, Inc.), Robert O'Dea (Motorola, Inc.), Paul Gorday (Motorola, Inc.)

We propose the use of IP-based broadband wireless protocols to address many of the applications needs in the Television White Space (TVWS) frequencies that will be available for secondary usage in the U.S. beginning in 2009. The work includes a discussion of TVWS physical and regulatory characteristic and a view of the TVWS usage models that may be applied in various market spaces, including the home, the enterprise, public safety and wireless mobile service providers. We show that a protocol based on IEEE 802.16e or a similar broadband wireless protocol could be adapted to meet many of the needs in this space.

Cognitive Radio Networks: Enabling New Wireless Broadband Opportunities (Invited Paper)

Dave Cavalcanti (Philips Research North America), Monisha Ghosh (Philips Research North America)

In this paper, we discuss the regulatory scenario for cognitive radio networks and give an overview of the emerging IEEE 802.22 standard, which is based on a dynamic spectrum access model, and provides new opportunities for wireless broadband access in rural area and remote communities. We discuss the main design challenges for the shared spectrum access model and describe how they are being addressed within the scope of the 802.22 networks. Some of the key design issues include incumbent protection, self-coexistence and spectrum management. We also highlight the new spectrum management model adopted in the 802.22 standard, which can be efficiently used under different regulatory models and rules.

Analysis of Aggregated Interference at DTV Receivers in TV Bands (Invited Paper)

Carlos Cordeiro (Intel Corporation), Sai Shankar Nandagopalan (Broadcom Corporation)

Several efforts are now underway to develop wireless technologies based on cognitive radios (CR) that can operate in the television (TV) band white space. One such example is the IEEE 802.22 Working Group (WG), which is formulating the first worldwide CR-based standard to operate in the TV bands. A mandatory requirement for any wireless technology operating in these bands is that it shall not cause harmful interfere with the passive TV receivers. In this paper we perform a comprehensive analysis of the effect of cumulative interference generated by the IEEE 802.22 system using circular cells and show how geometry plays an important role in the keep-out region. We then generalize our results and derive a generic formula to calculate the keep-out region for a typical deployment and for a variety of technologies.

Design and Verification of IEEE 802.22 WRAN Physical Layer (Invited Paper)
Sung Hyun Hwang (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Jung Sun Um (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Myung Sun Song (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Chang-Joo Kim (Radio Technology Group, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea), Hyung Rae Park (School of Electronics, Telecommunication, and Computer Engineering, Hankuk Aviation University, Korea), Yun Hee Kim (School of Electronics and Information, Kyung Hee University, Korea)

This paper describes the design and verification of IEEE802.22 WRAN physical layer. The WRAN physical layer is fundamentally based on the IEEE 802.16e system, but the OFDMA parameters including preamble structure and pilot pattern are newly designed by considering the WRAN channel environments. In this paper, we present the simulation models and results by using appropriate synchronization and channel estimation algorithms. From the results of those simulations, we can obtain 90% preamble detection probability at SNR more than -5 dB, and we can synchronize the CPE to the BS within 2 % of sub-carrier spacing at SNR more than about 1 dB. Moreover, by using the LMMSE algorithm to estimate the channel, we can reduce the performance degradation of 0.2~0.5 dB compared to ideal channel estimation. In conclusion, we have found that the proposed receiver meets the Functional Requirement Document (FRD) for WRAN physical layer.

A CR Platform for Applications in TV Whitespace Spectrum
Kihong Kim (Samsung Electro-Mechanics), Sungho Hwang (Samsung Electro-Mechanics), Junki Min (Samsung Electro-Mechanics), Seongsoo Lee (Samsung Electro-Mechanics), Kyungseok Kim (Chungbuk National University), Haksun Kim (Hanbat National University)

A cognitive radio platform for whitespace spectrum in UHF TV band is introduced. The purpose of the CR platform is to evaluate the feasibility of the unlicensed wireless service in the UHF TV band. The platform consists of RF, baseband modem and MAC including spectrum sensing function. The performance of the spectrum sensing function combined with wideband RF IC which is designed for mobile broadcasting service in multiple bands is presented.

SM4: Cooperative Sensing

Contention-Aware Spectrum Sensing and Access Algorithm of Cognitive Network (Invited Paper)

Hu Gang (National University of Defense Technology), ZHANG Qian (HKUST), XU Ming (HKUST)

The technology of sensing and access the potential available spectrum is always a hot topic for cognitive radio networks. Compare to the existing works, this paper proposes a new centralized sensing and access protocol which is based on the premise of contention-aware network flow. The target of this protocol is to maximize the expected throughput of the whole cognitive network. We have proven that finding the optimal sensing and access results under a fixed contention topology is NP problem. An approximated algorithm is proposed which is consisted by minimum clique cover and maximum matching algorithm. By detailed simulation, the performance of the approximated algorithm have at least 30% improvement comparing to the optimal sensing and access scheme which do not adopt the clique cover and maximum matching scheme.

Sensing UMTS Bands Using Cyclostationary Features and Cooperation Between Opportunistic Terminal

Joaquim Bastos (Instituto de Telecomunicacoes), Paulo Marques (Escola Superior de Tecnologia - Instituto Politecnico de Castelo Branco), Atilio Gameiro (Instituto de Telecomunicacoes - Universidade de Aveiro)

The Opportunistic Radio (OR) concept relies on the cognitive features of the OR terminals, namely the ability to adapt its transmitter parameters, based upon interaction with the RF environment in which it operates. An OR system operates in licensed frequency bands, exploiting opportunities and operating with a lower priority regarding the licensed system, implementing a spectrum pool mechanism. The most important constraint is that the OR network should always avoid harmful interference with the licensed system, therefore it should reliably detect licensed signals in the used band in order to avoid interfering with the licensed owner of that band. Given the importance of UMTS systems in current wireless communications, this paper is focused on 3G bands and addresses the problem of sensing weak UMTS signals. The proposed sensing algorithm exploits the cyclostationary features of UMTS signals and the cooperation between multiple OR terminals clustered in the OR network.

Detection Fusion by Hierarchy Rule for Cognitive Radio

Wenzhong Wang (Beijing University of Post and Telecommunications), Weixia ZOU (Beijing University of Post and Telecommunications), Zheng ZHOU (Beijing University of Post and Telecommunications), Yabin Ye (Create-Net, Italy)

Cooperation between cognitive radio nodes is indispensable in order to mitigate the sensitivity requirement on individual radio and increase the reliability of spectrum

sensing. Normally the fusion network is in parallel configuration and the conventional fusion rules are the k out of N rules because of their simplicity to manage. When the detection nodes are similar with each other i.e. their observations are from same probability distribution, the k out of N rules can make improvement to detection performance since they are equivalent to Neyman-Pearson criteria in this case. However the detection performance decreases greatly when the detection nodes are dissimilar due to fading and shadowing of radio channels especially when most of them are at low SNR states. The hierarchy fusion scheme we proposed in this paper incorporates both parallel and serial configuration and classifies detection nodes into different groups by their SNR levels. The receiver operating characteristic (ROC) of hierarchy fusion rule shows that the detection efficiency and reliability can be increased no matter the detection nodes are similar or dissimilar.

Sensor Pooling for Differential Sensing of Active and Idle Channels in Cognitive WPANs

Vojislav Misic (University of Manitoba, Winnipeg), Jelena Misic (University of Manitoba, Winnipeg, Canada)

Cognitive radio technology necessitates accurate and timely sensing of the primary users' activity on the chosen set of channels. We assume incomplete sensing, in which the number of sensing nodes is smaller than the number of channels; the results of sensing are cooperatively combined to form a coherent channel map. As the times when spectral opportunities end are more critical for network performance, idle channels should be sensed more frequently than the active ones. The paper presents a probabilistic analysis of this sensing policy, referred to as differential sensing, and investigates the range of values in which such, incomplete sensing is capable of maintaining an accurate view of the status of the working channel set.

Primary user detection in OFDM based MIMO Cognitive Radio

Rajarshi Mahapatra (Satyam Computer Services Ltd.), Vijaykumar Kuppusamy (Satyam Computer Services Ltd.)

In order to detect the presence of the primary user signal with high probability, spectrum sensing is a fundamental requirement to achieve the goal of cognitive radio (CR). This ensures efficient utilization of the spectrum. Energy detection is one of the technique to detect the primary users that are receiving data within the communication range of a CR user. In this work, detection performance of the primary user (PU) signal on CR receiver is investigated. In particularly, the OFDM based CR receiver detect the primary user OFDM signal, where CR receiver is equipped with multiple antennas based energy detector. We observe significant improvement in primary user detection with SLC based energy detection at the MIMO CRs in comparison to single antenna CRs.

SM5: Dynamic Spectrum Management

Resource Allocation for Cognitive Radios in Dynamic Spectrum Access Environment (Invited Paper)

Ekram Hossain (University of Manitoba), Dong Kim (Sungkyunkwan University (SKKU), Long Le (University of Waterloo)

We investigate the dynamic spectrum sharing problem among primary and secondary users in a cognitive radio network subject to QoS constraints for secondary users and interference constraints for primary users. For a scenario where only mean channel gains from secondary users to primary receiving points, which are averaged over short-term fading, are available, we derive outage probabilities for secondary users and interference constraint violation probabilities for primary users. Based on the analysis, we develop a framework to perform joint admission control and rate/power allocation for secondary users such that statistical guarantees on the violation probabilities of both the QoS and the interference constraints are achieved. Spectrum access by the secondary users can exploit the timevarying nature of the activity of the primary users, and thereby much higher throughput can be achieved compared to the case where primary users are assumed to be active at all time. Also, via extensive numerical analysis, throughput performances of primary and secondary users are investigated considering different levels of implementation complexity due to channel estimation.

Dynamic Spectrum Allocation with Second-Price Auctions: When Time is Money (Invited Paper)

*Anh Tuan Hoang (Institute for Infocomm Research, A*STAR, Singapore), Ying-Chang Liang (Institute for Infocomm Research, A*STAR, Singapore)*

We consider a dynamic spectrum access scenario in which transmission opportunities are allocated to users based on a second price, sealed bid auction. Each user experiences a time-varying channel and submits a bid for transmission right in each time slot. A base station collects bids from all users and allocates the channel to a user with the highest bid, who then pays the price equal the second highest bid. The distinctive feature of our model is that it treats time as money and allows each user to bid and to pay for the transmission rights using his/her own communication time. For each time slot, the value of a bid submitted by each user is equal the amount of time he/she promises to forfeit to the base station for the right to transmit during the remaining of the time slot. That means the base station collects part of each time slot from the winning user for its own usage and allocates the rest to the winning user. Users can vary their bids based on their channel conditions, subject to constraints on average budgets. From the users' point of view, we show that there exists Nash equilibrium bidding strategies in the two-user case. From the base station's point of view, we investigate how average budget constraints should be set to balance between base station's revenue and users' satisfaction.

Spectrum Pool Reassignment for Wireless Multi-hop Relay Systems
Ashish Pandharipande (Philips Research), Chin Keong Ho (Institute for Infocomm Research)

We consider a wireless multi-hop relay system that operates on secondary sharing basis in licensed spectrum. The system employs OFDM-based spectrum pooling to avoid harmful interference to licensed systems. An OFDM-based spectrum pool comprises of a set of OFDM subchannels that correspond to white space spectrum regions. The proposed relay system comprises of a source node that transmits data to a destination node in multi-hops using multiple relay nodes. Communication over node pairs occurs on an available spectrum pool. At each receiving intermediate node, received data symbols are amplified, permuted and then forwarded on. Spectrum pool reassignment comprises determination of the permutation mapping at each intermediate node. We consider the problem of maximizing the system capacity by determining the optimum spectrum pool reassignment. We show that each relay can determine the optimum permutation mapping based on the {\it{effective}} signal to noise ratios in the previous hops and the signal to noise ratio in the next hop, while preserving system optimality.

Aggregation Aware Spectrum Assignment in Cognitive Ad-hoc Neftworks
Dawei Chen (The Hong Kong University of Science and Technology), Qian Zhang (The Hong Kong University of Science and Technology), Weija Jia (City University of Hong Kong)

Contiguous spectrum assignment generates many small spectrum fragments that cannot be fully utilized, which leads to low spectrum utilization. With the development of advanced wireless radio technology, especially Discontiguous Orthogonal Frequency Division Multiplexing (DOFDM), discontiguous spectrum access and spectrum aggregation in a single radio has become possible. With the help of discontiguous spectrum access, the small spectrum fragments could be aggregated and further utilized, which can dramatically improve the spectrum utilization efficiency. Based on this observation, we propose Aggregation-Aware Spectrum Assignment (AASA), a spectrum assignment algorithm in cognitive ad-hoc networks. In AASA, we propose a spectrum assignment method that takes spectrum aggregation into consideration. Moreover, we prove that AASA optimizes the spectrum assignment and maximizes the number of users that can be supported in the system. Simulation result shows that AASA significantly increases the spectrum assignment efficiency compared with the existing solutions.

Game Theoretic Analysis of Joint Channel Selection and Power Allocation in cognitive radio networks
Hao He (UESTC), Jie Chen (UESTC), Shoufeng Deng (UESTC), Shaoqian Li (UESTC)

In this work, we study joint channel selection and power allocation problem in cognitive radio network by formulating the potential game model. First, under the interference constraint, a nonlinear optimization problem is formulated for improving the total throughput and considering the fairness in cognitive radio network. we also define the special objective function for each transmitting node and formulate a potential game to

solve this problem distributively. The Nash equilibria of this potential game is investigated. It is shown that the distributed sequential play converges to a Nash equilibrium point and quickly satisfies the interference constraint. Finally, through simulations, the performances are examined and we further investigate the relationship between the parameters of the objective function and the performances of the whole cognitive radio network.

SM6: Physical Layer Design

Performance Evaluation of Adaptive Non-contiguous MC-CDMA and Non-contiguous CI/MC-CDMA for Dynamic Spectrum Access

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In this paper, we present a quantitative performance evaluation of non-contiguous multi-carrier code vision multiple access (NC-MC-CDMA) for cognitive radio in a dynamic spectrum access (DSA) network. In a DSA network, multi-carrier based cognitive radio transceivers need to deactivate some of its subcarriers to avoid interference to primary users. However, by deactivating subcarriers, orthogonality among different spreading codes are lost, leading to poor BER performance. The performance of the NC-MC-CDMA can be improved by adaptive spreading code adjustment to compensate for the loss of orthogonality. However, since Hadamard-Walsh codes only exist for certain code length, loss of orthogonality can only be minimized instead of eliminated for many cases. On the other hand, orthogonal Carrier Interferometry codes exist for code length of any integer. Hence, by applying non-contiguous CI/MCCDMA into DSA, the loss of orthogonality among spreading codes caused by deactivating subcarriers can be eliminated. As a direct result, adaptive NC-CI/MC-CDMA significantly outperforms adaptive NC-MC-CDMA using Hadamard-Walsh codes.

On the Impact of CFO for OFDM Systems with Un-equal Gain Diversity Schemes over Small-term Fading

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The system performance of OFDM (orthogonal frequency division multiplexing) with dual branch SC (selection combining) diversity over small scale fading correlated channel is investigated in this paper. The performance of average BER (bit error rate) of the OFDM system is calculated by adopting the results with an alternative expression of the Q-function. The correlated-Weibull fading distribution is applied to characterize the propagation fading channel. Moreover, the assumption of CFO (carrier frequency offset) existing between subcarrier is other scenario considered in this paper. It is worthwhile noting that the system performance of an OFDM system with SC diversity is definitely dominated by transmission environments, that is, except fading parameters (of Weibull distribution) of fading statistics will be the most important reason to decide whether the system performance of an OFDM system is well or not, the CFO is another phaneoman affects the performance too. Furthermore, both of equal and unequal branch gain of the received waveform at the output of SC diversities is assumed in the discussion for OFDM communication systems.

Efficient scheme for DOA estimation of multipath clusters in WiMedia UWB systems
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UWB systems are expected to find widespread use in future short range applications. Increasing popularity of these devices will require management of occupied spectrum in spatial domain to keep the interference low. In Ultra Wide Band (UWB) communication systems, one encounters many multipath components. By optimally forming beams in the direction of the principal multipath clusters, one can achieve optimum spectrum efficiency. The number of components would depend on the sampling rate as the number of resolvable components depends on it. Besides, many of the multipath components would be coming from the same cluster. The estimation of the Direction of Arrival (DOA) of these clusters is very useful to focus the transmit power in the optimum direction. A new algorithm, exploiting the known pilot signals of multiband UWB systems for estimation of DOA of clusters is proposed recently. By making use of a new matrix incorporating the cross correlation between the focused UWB signal and the known pilot signal of the transmitted data in each array element, one would be able to separate the multipath clusters from a single source. This paper looks at reducing the number of receivers required for implementing the algorithm. UWB System makes use of the preample to synchronize the incoming data. Hence, one can employ a central processor to sample the data from individual sensors in a time multiplexed fashion. This time multiplexed sampled data can be used for finding the expected value of correlation with known reference data. This would allow usage of fewer receivers to achieve the same level of performance. Computer experiments are included to verify the performance of the proposed algorithm with and without receiver time multiplexing.

Adaptive Two-Dimensional Channel Estimation Scheme for OFDM Systems
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This paper presents an adaptive low complexity channel estimation scheme for orthogonal frequency division multiplexing (OFDM) systems in the time-varying multipath fading channels. The proposed scheme is designed based on the pilots, which are arranged at different locations for different OFDM symbols. Based on the proposed channel estimation scheme, the channel frequency response of the current OFDM symbol is estimated from the current and neighboring pilots and no addition or multiplication is required. It is shown that the feasibility of the proposed scheme depends on the characteristics of the channels. We also analyze the performance of the proposed channel estimation scheme in the time-varying fading channels. Computer simulations are conducted to evaluate the performance of the proposed scheme. The simulation results are also compared with the ML algorithm and the system with ideal channel information (ICI). It is shown by the computer simulations that the performance of the proposed scheme is close to the ML algorithm in the slow fading channel. The implementation complexity is also discussed in this paper. It is shown that the complexity of the proposed channel estimation scheme is less than the linear interpolation and ML algorithm. Therefore, it is suitable for wireless local area network (WLAN) and wireless metropolitan area network (WMAN) applications.

Phase Noise Analysis of PLL Based Frequency Synthesizers for Multi-Radio Mobile Terminals

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This paper deals with phase noise analysis and design aspects of PLL based frequency synthesizers for cognitive multi-radio mobile terminals. Principal features of PLL based frequency synthesizers are presented and simulated. This document describes various issues of the loop filter design and the overall impact on the frequency synthesizer performance in terms of the phase noise, settling time and the spurious suppression capability. Phase noise requirements for main communication standards in the frequency band 800 MHz to 6 GHz are investigated as well.