Preface

The aim of this book, the first of two volumes, is to present selected research that has been undertaken under COST Action IC0902 "Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneous Wireless Networks" (http://newyork.ing.uniroma1.it/IC0902/). COST (European Cooperation in Science and Technology) is one of the longest-running European frameworks supporting cooperation among scientists and researchers across Europe.

Written by leading researchers from both academia and major industrial research laboratories, this book will provide electrical, R&D electronic and communication engineers, as well as researchers, undergraduate, graduate, and postgraduate students with a unique and comprehensive overview of recent advances in cognitive radio (CR) and networks.

The book will allow the reader to have access to avant-garde results, in the CR and cooperative heterogeneous coexistence field, in a thorough and detailed way.

Topics covered by the book include newly developed techniques on spectrum sensing algorithms for cognitive white-space systems using either single or multiple antennas, and novel blind free-bands detectors exploiting cyclic autocorrelation function sparsity. The reader will also explore learning and optimization techniques and mechanisms based on biomimetic approaches for Self-Organization in Macro–Femtocell Coexistence; these methods are based on the recently developed "Docition" concept for cognitive networks. The book further includes extensive discussions regarding issues related to the implementation of the different steps of the cognitive cycle, and, in particular, on reasoning. Application of such concepts to cognitive networks allows defining a potential architecture for their integration into current TCP/IP networks. Indeed, using the cognitive paradigm represents a way toward (i) addressing the multiple timescales of operation of a network and (ii) gaining additional information on the cause–effect relationships between network configuration and performance. A very interesting chapter that describes how cognitive networking can be implemented to support green network operation, proposing a test case and demonstrating its potential in a 3G cellular context, is also included in the book. A complete description of the latest groundbreaking field trials is also available to the reader along with the current and future market requirements and so-called killer applications. Finally, in the last chapter, main conclusions and recommendations regarding the available test beds are reported.

A brief description of each of the chapters is as follows.

Chapter 1, by A. Mariani et al., focuses on "Recent Advances on Wideband Spectrum Sensing for Cognitive Radio". Spectrum sensing plays a fundamental role in cognitive radio networks allowing the discovery of spectrum opportunities and enabling primary user protection. Many spectrum sensing techniques have been proposed in the literature, from the most popular algorithms such as energy detection and feature detectors, to most advanced techniques such as eigenvalue-based strategies and cooperative approaches. Most of these techniques have been conceived to assess the occupancy of primary users within a single frequency band. Improved knowledge of the surrounding radio environment can be reached exploiting wideband spectrum sensing, which consists in a joint observation of multiple frequency bands and joint detection on the occupancy of each sub-band. In this chapter, a novel methodology for wideband spectrum sensing based on an information theoretic approach is provided. This technique does not require the setting of a decision threshold, which is a problem for many spectrum sensing algorithms due to the dependence on unknown parameters or difficulties in the statistical description of the decision metrics. A general formulation of the problem is also provided in this chapter, which is valid for any kind of spectral representation, and then specifies the analysis for the case in which simple DFT is used. Performance analysis is provided to the reader and is based both on numerical simulations and laboratory tests using SDR implementation.

Complexity of spectrum activity, and its effect on opportunistic access, is the topic addressed by I. Macaluso et. al., in Chap. 2. The authors analyse the relationship between the number of observed channels, the duty cycle (DC), the complexity of each channel activity, and the performance of a learning-enhanced technique for opportunistic spectrum access. The findings show that the probability of finding a free channel among a group of observed ones strongly depends on the DC and the complexity of the channel activity. Moreover, it is shown that if a cognitive radio is able to select the channels with best characteristics, reducing the number of observed channels has little effect on the performance of the learning algorithm. Hence, a pre-processing phase that a cognitive radio can use to focus on a subset of channels is introduced, which results in a more effective spectrum exploitation. In particular, the authors show that a cognitive radio system can use the DC and the Lempel–Ziv complexity to characterize spectrum usage and select a subset of channels yielding to best performance of the learning technique. The reader will notice that the introduction of the pre-processing stage, which is akin to the orientation phase of the cognitive cycle reduces the number of observed channels, thus, impacting the amount of resources devoted to the sensing stage.

Chapter 3, by S. Dikmese et al., explores the effect of deviating from the simplistic signal model commonly utilized in modelling energy detection in spectrum sensing. The first part of the chapter briefly introduces basic energy detection models, as well as the concept of wideband, multi-mode spectrum sensing using Fast Fourier Transform (FFT) and analysis filter bank for spectrum analysis. The second part of the chapter examines the effects of various forms of frequency dependency in energy detection. First, the effect of a non-ideal frequency response of the sensing receiver is analyzed and related modifications to optimize energy detection performance are developed. Second, the effects of various forms of frequency dependency in energy detection are analyzed. Next, the authors address the case where the sensing window in the time-frequency plane includes both zones where the PU signal is present and zones where it is absent, leading to mixed decision statistics. The case of non-flat primary user spectrum is addressed in the last part of this chapter, and includes the effect of non-flat transmitted spectra and channel frequency selectivity.

Chapter 4, by D. Riviello et al., focuses on spectrum sensing algorithms and techniques for secondary users operating in digital TV white-spaces. Here, the primary signal conforms to the ETSI DVB-T or DVB-T2 standard, and consists in a continuous sequence of OFDM symbols. Since no further assumptions are made on primary signal characteristics, results obtained for DVB-T(2) can be straightforwardly extended to any standard using OFDM modulation. Note that both single-antenna and multi-antenna techniques are considered in this chapter; performance is assessed and compared against simple sensing techniques such as energy detection.

Z. Khalaf and J. Palicot propose in Chap. 5 a new blind free-band detector exploiting the cyclic autocorrelation function (CAF) sparsity. They first show that the CAF of a linearly modulated signal is a sparse function in the cyclic frequency domain. Using this property, the authors propose a new CAF estimator that uses compressed sensing with Orthogonal Matching Pursuit (OMP). This new proposed estimator outperforms classic estimators operating under similar conditions. Several cases are analysed with and without using filtering at the transmission and reception sides. The impact of a propagation channel is also considered in the analysis. Using this new CAF estimator, in the second part of this chapter, the performance of two blind free-bands detectors are analysed and compared. The first is a soft version of the proposed CAF, where it is assumed that two estimated CAF of two successive packets of samples have close cyclic frequencies. The second estimator uses the symmetry property of the Second Order Cyclic Autocorrelation.

Chapter 6, by A. Georgakopoulos et al., addresses novel concepts on inter-system coexistence and cooperation through cognitive control channels. Cognitive management systems have been proposed as an extension of the ETSI/RRS functional architecture in order to enable the coordination of the network elements with the operators infrastructure. In the functional architecture, two management systems are presented, namely: (i) the Cognitive Management System for the Coordination of the Infrastructure (CSCI), which is responsible for the detection of situations where an Opportunistic Network (ON) would be useful (prior to the formation of the ON) and (ii) the Cognitive System for the Management of the Opportunistic Network (CMON), which is responsible for the creation, maintenance and termination of a given ON based on the context and policy information provided by the CSCI. Both systems are separate functional blocks of the functional architecture and interact with other components via pre-specified interfaces. For the cooperation of CSCIs and CMONs, specific mechanisms need to be defined in order to increase the accuracy of obtained knowledge on the context of the operational environment. Therefore, this chapter focuses on the definition of required interfaces that are introduced in order to enable communication between the cognitive management systems and also to the related groups of information that is needed to be conveyed between these systems in order to ensure proper interaction. Furthermore, high-level evaluation of the load associated with the aforementioned groups of information is provided based on analytical models.

Chapter 7, by S. Nallgonda et al., covers cooperative spectrum sensing with censoring of cognitive radios, focusing on the case of Rayleigh fading under majority logic fusion. The chapter starts on a comparative analysis of the performance of cooperative spectrum sensing (CSS) under different hard decision fusion rules such as AND logic, OR logic and Majority logic. Also soft information fusion such as maximal ratio combining (MRC)-based fusion is considered, if the sensing channel is subject to fading and shadowing, including Rayleigh/Rician fading and Lognormal shadowing. The impact of fading and shadowing on the performance of CSS is analyzed in terms of missed detection, false detection and total error probabilities. Complementary receiver operating characteristics (RoC) are also discussed under several scenarios of fading and data fusion. The second part of the chapter focuses on the performance of a CSS scheme with censoring of CRs, based on the quality of the radio link in the R-channel. In this chapter, two censoring schemes are investigated: (i) rank-based, where a subset of SUs, associated with best estimated channel coefficients, are selected out of all available SUs and (ii) threshold-based, where an SU is selected if its R-channel amplitude is above some pre-selected threshold level. The performance of these two censoring-based CSS schemes is studied in the presence of Rayleigh and Nakagami-m fading in the R-channels, considering majority logic or MRC fusion rules at FC. Note that the studies presented in this chapter are useful in designing energy-constrained cognitive radio networks.

Chapter 8, by M.-G. Di Benedetto et al., focuses on the medium access control (MAC) for distributed cognitive ultra wide band (UWB) networks. It is claimed that the MAC should be specifically conceived around the impulsive characteristics of the UWB radio signal, and as such foresee and eventually optimize strategies for power sharing and management. MAC functions that can benefit from specific UWB features are discussed, and sensing in the presence of potential narrowband coexisting networks is analyzed. Interference models for impulsive communication systems are also taken into consideration and reviewed, with the aim of defining packet error rate. In particular, the pulse collision model is compared against traditional interference models based on the standard Gaussian approximation. Performance evaluation using the proposed models incorporate theoretical and simulation analyses of MAC properties that are peculiar to impulsive communications.

The notion of Radio Environmental Maps (REMs) has become very prominent in the cognitive radio and dynamic spectrum access field. REMs can be seen as databases or knowledge bases storing different kinds of radio environmental information, such as locations of transmitters and receivers, models of the propagation environment and various spatial/temporal spectrum usage measurements.

L. Gavrilovska et al., address this topic in Chap. 9. An extended study on the "Integration of Heterogeneous Spectrum Sensing Devices Towards Accurate REM Construction" is reported. The reader is introduced to a recently developed generic REM construction architecture capable of integrating heterogeneous spectrum sensing devices by combining the spectrum sensing and the database approach for accurate radio environmental mapping with a specific focus on the device calibration procedure as a quintessential part of the integration process. Theoretical and practical aspects related to the realization of a REM prototype are discussed, as well as on-the-field experimental results obtained with different hardware.

Chapter 10, by A. Galindo-Serrano et al., further addresses the Radio Environment Map topic. The main issue here is to introduce an automatic and remote self-optimization process based on geo-location information exploitation for cellular coverage optimization. Specifically, the REM is used for cellular network coverage hole detection purposes. This coverage hole detection approach drastically reduces the required drive tests and enhances the network with self-responsive capabilities to handle key obstacles toward cellular networks autonomy. In this chapter, the REM is handled in a more general Cognitive Radio (CR) context than TV white-spaces, and it is considered as a mean to represent spatio-temporal characteristics of the radio environment by using concepts and tools from spatial statistics, like point processes, spatial random fields, pair correlation functions, point interaction models, spatial interpolation techniques, etc. Coverage may in fact be the most important and highest-priority target for cellular operators.

Chapter 11, by A. Imran and L. Giupponi, presents the use of several bio inspired approaches, called biomimetics, for the design of Self-Organization (SO) in heterogeneous network scenarios, and in particular the use of learning, game theory and optimization as Biomimetic approaches for SO in Macro–Femtocell Coexistence. Mainly, these approaches are further categorized in indirect and direct biomimetics. Under the concept of indirect biomimetics, the authors discuss in detail the emerging paradigms in learning theory that have been recently shown to have strong potential for designing SO solutions in heterogeneous networks such as Start-up Docition, IQ-Driven Docition, Performance-Driven Docition and Perfect Docition. The authors further investigate a rather under explored paradigm of direct biomimetic. Building on case studies of self-organizing systems in nature, the authors extracte the generic SO design principles, that can be used as a direct biomimetic approach for designing distributed, scalable and agile solutions, to many problems in complex heterogamous networks.

Chapter 12, by H. Bogucka and M. Parzy, focuses on a practical perspective of cooperation and competition for spectrum sharing in cognitive radio networks. In this chapter, practical issues of cooperation among cognitive radio nodes competing for available resources in decentralized network are considered. It is pondered how the theory of competition and cooperation (game theory) meet the practice, by discussing the quantitative metrics of the cost of avoiding cooperation (the Price of Anarchy—PoA), of having limited knowledge of the competitors (the Price of Ignorance—PoI), and of limited time for learning the network environment (the Price of Impatience—PoIm) in dynamically changing radio channels.

This chapter provides the description of practical approaches to spectrum sharing and allocation, which make use of limited, i.e., intentionally reduced information, that the CR nodes have to exchange.

Chapter 13, by L. Abarca et al., consists in a synopsis on security threats in cognitive radio networks (CRNs), specially focusing on the Primary User Emulation (PUE) attack. The chapter includes details on how the location of a transmission source can be a valuable tool to detect PUE attacks, whenever the position of true primary transmitters is known, as it is the case for TV towers in IEEE 802.22 networks. Due to its wireless nature, CRNs inherit most of the threats already reported in the literature in the context of wireless networks. However, the flexibility and reconfigurability capabilities of these networks not only may make conventional attacks easier but also expose them to new risks. In the first part of this chapter, the reader has an outline on main threats to cognitive radio networks, providing a classification of the current threats and detailing the new specific security challenges. The second part describes the behaviour of the PUE attack, with its different implementations and variants. The third part describes a novel method able to detect PUE attacks, based on a cooperative location technique.

Chapter 14, by F. Granelli et al., addresses "Cognition as a Tool for Green Next Generation Networks", with a focus on reasoning. Network performance is a multifaceted concept, including simple measures such as throughput as well as user-level QoS, and a recently added parameter to the equation, i.e., the power consumption. The need for identifying suitable methodologies to optimize performance from the above viewpoints, including energy saving, is driving interest of research toward the emergence of the "green networks". Green networking represents an appropriate scenario where cognition and adaptation are required. How cognitive networking can be implemented to support green network operation is discussed in this chapter, also based on a test case that demonstrates its potentials in 3G cellular contexts.

Chapter 15, by K. Katzis et al., addresses the topic of no less importance "Testbeds and Implementation Issues". Efficient design of CR engines requires the capability of experimentally verify the proposed solutions, and the identification of engine components and of corresponding implementation choices is a fundamental step toward this direction. Within this context, this chapter aims at presenting testbeds and related implementation issues, including CR engine architecture regarding its software and hardware components and available technologies, available platforms and finally implementation issues of CR engines related to standardization.

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We hope that the book will provide the reader with comprehensive treatises of salient aspects in the field of "Cognitive Communications and Cooperative HetNet Coexistence". We also hope that the book will motivate the research community, especially in young researchers, toward solving the several issues that are left open for future research.

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