Preface

The aim of this book is to present, in a tutorial perspective, the visions and trends for future wireless networks and technologies based, inspired, and learned from Cognitive Radio (CR) investigations that have been carried out within the framework of the 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 programs supporting cooperation, sharing, and dissemination among scientists and researchers across Europe.

This book has been written by leading researchers, that are first-hand experts in a wide range of fields and disciplines, from both Academia and industrial players. The main purpose of the manuscript is to provide scientists, researchers, wireless communication network engineers and professionals, and graduate students with a widely comprehensive tutorial tool for understanding and developing cognitive radio network (CRN) technology components, based on the latest state of the art in the field.

The book will allow the reader to access both fundamental and advanced knowledge spanning from the design of CRN air interfaces to network architectures and algorithms, following a bottom-up approach. Furthermore, the book includes practical help in setting up essential investigation tools such as simulators and experimental test beds, in the form of direct step-by-step how-to.

Topics covered by the book include filter bank multicarrier systems that try to incorporate coexistence properties starting from the design of the CR air interface. Furthermore, recent advances in signal processing are presented in the context of interference mitigation. The reader will also get access to insights on how to design the link layer of CR, including specific highlights on essential features such as spectrum sensing and dynamic spectrum access. Climbing up in the traditional layered architecture, the book will also provide trending visions on how to evolve the internet architecture and protocols in dynamically adaptive, cognitive-oriented ones. An interesting chapter will provide also regulatory perspectives on the possible usage of the spectrum by CRN players, including economical and market reflections. Finally the book will dive into the practical aspects that a researcher or an engineer can face on the everyday job: how to simulate or develop CRN systems. Three chapters cover the most hot topics in the field, using open-source widely available tools, such as software simulations, software defined radio tools and developments, and embedded systems.

A brief description of each chapter is as follows.

In Chap. 1 by Medjahdi et al. the authors provide a tutorial overview on multicarrier techniques, which are offering flexible access to possible new spectrum opportunities. Indeed, OFDM, which is the most commonly used multicarrier technique, has been adopted in IEEE 802.22 standard for unlicensed wireless regional area network (WRAN) considering cognitive communications on the unused TV bands. Unfortunately, OFDM presents some weaknesses. In fact, the redundancy, caused by the insertion of the cyclic prefix mandatory part of the transmitted OFDM symbol, reduces the useful data rate. Furthermore, the poor spectral localization of the OFDM subcarriers due to the large sidelobes induces not only an additional spectral loss but also interference problems with unsynchronized signals. These shortcomings have stimulated the research of an alternative scheme that can overcome these problems. An enhanced physical layer based on the filter bank processing called filter bank-based multicarrier (FBMC) technique has been proposed in various works. A major improvement in spectrum efficiency and better flexibility for system coexistence can be achieved by FBMC thanks to the use of spectrally well-localized waveforms. The advantages and the drawbacks of the classical OFDM are first discussed in the chapter. Next, the authors will introduce the different schemes of FBMC systems: Filtered multitone (FMT), cosine modulated multitone (CMT) and staggered multitone (SMT, also called FBMC-OQAM). After introducing a theoretical background of the FBMC transmission, the polyphase implementation of the filter bank transceiver and the prototype filter design are reviewed. Finally, the chapter highlights the interest of FBMC spectrum sharing and investigate coexistence issues.

Interference alignment (IA) has been widely recognized as a promising interference mitigation technique since it can achieve the optimal degrees of freedom in certain interference limited channels. This topic is then addressed by Sharma et al. in Chap. 2. IA allows in fact the coexistence of two heterogeneous wireless systems in an underlay cognitive mode. The main concept behind this technique is the alignment of the interference on a signal subspace in such a way that it can be filtered out at the non-intended receiver by sacrificing some signal dimensions. This chapter starts with an overview of the IA principles, the degree of freedom (DoF) concept, and the classification of existing IA techniques. Furthermore, this chapter includes a discussion about IA applications in CR networks. Moreover, a generic system model is presented for allowing the coexistence of two heterogeneous networks using IA approach while relevant precoding and filtering processes are described. In addition, two important practical applications of the IA technique are presented along with the numerical results for underlay spectral coexistence of (i) femtocell-macrocell systems, and (ii) monobeam-multibeam satellite systems. More specifically, an uplink IA scheme is investigated in order to mitigate the interference of femtocell user terminals (UTs) towards the macrocell base station (BS) in the spatial domain and the interference of multibeam satellite terminals towards the monobeam satellite in the frequency domain.

Chapter 3 by Yilmaz et al. will provide a detailed technical insight into latest key aspects of cooperative spectrum sensing. The authors focus on fusion strategies, quantization enhancements, effect of imperfect reporting channel, cooperative spectrum sensing scheduling, and utilizing cooperatively sensed data via radio environment map (REM). The sharing of local observations between the secondary users and the fusion center is one of the most crucial factors that determines the performance of cooperative sensing. The detection performance is determined by the quality of local observations and the quality of the information received by the fusion center. Therefore, the number of quantization bins, the number of bits sent for sensing reports, the global decision logic, the imperfections in the reporting channel, and the erroneous reports due to malfunctioning or malicious secondary devices affect the system performance. Furthermore, there are many channels to sense while the cooperating nodes are few, therefore coordinating the sensing nodes for detecting high quality channels is necessary. Cooperative sensing scheduling concentrates on the scheduling of cooperative nodes and the channels to be sensed. This chapter also focuses on the energy consumption problem that becomes more severe if the users are mobile. The components of energy consumption dedicated to cooperative sensing are analyzed and optimal and sub-optimal (but efficient) sensing scheduling mechanisms are discussed in order to reduce the sensing energy consumption of the network. Once the spectrum has been sensed cooperatively, the outcomes can be utilized via REM, which can be considered as a crucial part of the cognitive engine located at the network. The sensed information may also play a crucial role in the generation of REM. Hence, this chapter also focuses on how the sensing measurements could be utilized for REM construction.

The endeavor of categorizing the existing cognitive-MAC (C-MAC) protocols requires definition of general classification frameworks or layouts that merge most of the aspects of the protocols in a single unified presentation. Chapter 4 by Gavrilovska et al. introduces the C-MAC cycle as a general classification and systematization layout for C-MAC protocols. The C-MAC cycle originates from the idea that the MAC layer in spectrally heterogeneous environments should provide support for three generic technical features: radio environmental data acquisition; spectrum sharing; and control channel management. The inclusion of these generic technical features is necessary in CRNs for improving the network performance and achieving spectrum efficiency gain while providing maximal level of protection for the primary system. This chapter will present extensive survey on the state-of-the-art advances in C-MAC protocol engineering by reviewing existing technical solutions and proposals, identifying their basic characteristics and placing them into the C-MAC cycle, with emphasis on the modularity of the C-MAC cycle. It provides an overview of a large number of technical details concerning the three generic functionalities (i.e. the radio environmental data acquisition, the spectrum sharing and the control channel management) as the main building blocks of the C-MAC cycle. Three use cases (each in different generic functional group) illustrate the capabilities of the proposed C-MAC cycle layout. In more detail, the first use case theoretically presents and practically evaluates cooperative spectrum sensing based on estimated noise power. The results illustrate the effect of estimating the noise variance on the detection capabilities of the majority voting and equal gain combining cooperative spectrum sensing strategies. The second use case presents advanced and computationally efficient horizontal spectrum sharing strategy for secondary systems based on node clustering and beamforming. Finally, the last use case presents and assesses a multiuser quorum-based multiple rendezvous strategy for control channel establishment in distributed CRNs.

In Chap. 5 by da Costa et al. the authors dive in the ever-growing demand for mobile broadband that is pushing towards the utilization of small cells, including metrocells, picocells and femtocells. In particular, the deployment of femtocells introduces significant challenges. Firstly, the massive number of expected femtocells cannot be deployed using the traditional planning and optimization techniques. This leads to uncoordinated deployment by the end-user. Secondly, the high density of femtocells, including vertical reuse, leads to very different inter-cell interference patterns than the ones traditionally considered in cellular networks. And last, but not least, the possibility of having closed-subscriber-groups aggravates the inter-cell interference problems. In order to tackle these issues the authors consider the implementation of some aspects of CR technology into femtocells, leading to the concept of cognitive femtocells (CFs). This chapter focuses on state-of-the-art techniques to manage the radio resources in order to cope with inter-cell interference in CFs. Different techniques are presented as examples of gradually increasing sophistication of the CFs, allowing for dynamic channel allocation, dynamic reuse and negotiated reuse based on information exchanged with neighbor cells.

Granelli et al. are instead moving the discussion from the wireless domain into the networking one in Chap. 6. As a matter of fact, the requirement to support an always increasing number of networking technologies and services to cope with context uncertainties in heterogeneous network scenarios leads to an increase of operational and management complexity of the Internet. Autonomous communication protocol tuning is then crucial in defining and managing the performance of the Internet. This chapter presents an evolutionary roadmap of communication protocols towards cognitive Internet in which the introduction of self-aware adaptive techniques combined with reasoning and learning mechanisms aims to tackle inefficiency and guarantee satisfactory performance even in complex and dynamic scenarios. In this chapter, the authors provide a survey and comparison between existing adaptive protocol stack solutions, reviewing the principles of cross-layer design as well as the agent-based and AI based self-configuration solutions. The fundamental principles of cognitive protocols, such as adaptation, learning, and goal optimization, are presented along with implementation examples.

Introducing cognitive mechanisms at the application layer is instead investigated by Boldrini et al. in Chap. 7 and it may lead to the possibility of an automatic selection of the wireless network that can guarantee best perceived experience by the final user. This chapter investigates this approach based on the concept of quality of experience (QoE), by introducing the use of application layer parameters, namely key performance indicators (KPIs). KPIs are defined for different traffic types based on experimental data. A model for an application layer cognitive engine is presented, whose goal is to identify and select, based on KPIs, the best wireless network among available ones. An experimentation for the VoIP case, that foresees the use of the one-way end-to-end delay (OED) and the mean opinion score (MOS) as KPIs is presented. This first implementation of the cognitive engine selects the network that, in that specific instant, offers the best QoE based on real captured data.

Another important piece of information that CRNs can use for optimizing services is the location of the CR terminal. This aspect will be clarified by Chochliouros et al. in Chap. 8. Starting from a general survey of several among the critical capabilities and/or features characterizing CRNs, in the context of actual European standardization efforts, the chapter will present an overall and harmonized technical concept for future CR systems, especially by discussing several options affecting the future evolution of radio technologies and network architectures towards more flexible and reconfigurable CR systems, as the latter are expected to increase the efficiency of the overall spectrum usage by offering new sharing opportunities and thus to provide more flexibility to applications-services.

In Chap. 9 Georgakopoulos et al. will provide a trending vision on the architectural possibilities that are offered to wireless mobile broadband networks for jointly satisfying complex context of operations as well as system requirements like QoE (quality of experience) and energy and cost efficiency. Introduction of intelligence in the Cloud-RANs will lead towards this direction by providing the necessary decisions based on the received inputs. Cloud-RANs have the capabilities to adapt their network topology and resource allocation so as to realize environmental-friendly and cost-efficient solutions by moving elements of the legacy RAN to cloud-based infrastructures. The authors will try to provide, in the chapter, an indication on the elements of the approach as well as the identification of the benefits from such a concept.

The purpose of Chap. 10 by Doyle and Forde is instead to give a regulatory perspective on CR, that can be seen as a natural part of the roadmap for advanced communication systems and from this standpoint can be dealt with within the context of normal regulations. However one of the key and unique advantages of CR is that it is an enabler of spectrum sharing in its many forms. Hence the main part of this chapter is devoted to different regulations in spectrum sharing and the implications for CR. It looks at regulations which are in existence as well as emerging regulations. The chapter also provides a generic framework in which to place different sharing regimes.

Chapter 11 by Caso et al. is leading the discussion in the practical everyday issues of researchers and engineers. In fact, a widespread methodology for performance analysis and evaluation in communication systems engineering is network simulation. It is widely used for the development of new architectures and protocols. Network simulators allow to model a system by specifying both the behavior of the network nodes and the communication channels, and CR-related research activities have been often validated and evaluated through simulation too. Following this approach, this chapter presents an ongoing effort towards the development of a CR simulation framework, to be used in the design and the evaluation of protocols and algorithms. OMNeT++, in combination with MiXiM framework functionalities, was chosen as the developing platform, thanks to its open source nature, the existing documentation on its architecture and features, and the user-friendly integrated development environment (IDE).

More and more researchers are entering the idea of research-oriented test beds. Unfortunately, it is very difficult for a wide number of research groups to start with their own set up, since the potential costs and efforts could not pay back in term of expected research results. Chapter 12 by Cattoni et al. provides a tutorial, first-hand overview on software defined radio solutions, which offer an easy way to communication researchers for the development of customized research test beds. While several hardware products are commercially available, the software is most of the times open source and ready to use for third party users. Even though the software solution developers claim complete easiness in the development of custom applications, in reality there are a number of practical hardware and software issues that research groups need to face, before they are up and running in generating results. With this chapter the authors will provide a tutorial guide, based on direct experience, on how to enter in the world of test bed-based research, providing both insight on the issues encountered in everyday development, and practical solutions. Finally, an overview on common research-oriented software products for SDR development, namely GNU radio, Iris, and ASGARD, will be provided, including how to practically start the software development of simple applications.

In Chap. 13 Šolc et al. describe their experiences with the design, deployment and experimental use of the LOG-a-TEC embedded, outdoor CR test bed, based on the VESNA sensor node platform. The authors will describe the choice of experimental low-cost reconfigurable radio frontends for LOG-a-TEC and discuss the potential capabilities of custom designs. The core part of this chapter will provide practical experiences with designing the embedded testbed infrastructure, covering topology design and performance evaluation of the management network as well as considerations in the choice of network protocols employed in the LOG-a-TEC testbed. Use cases using LOG-a-TEC test bed for performing experiments are also covered, one relevant to the investigation of coexistence of primary and secondary users in TV white spaces and the other addressing power allocation and interference control in the case of shared spectrum.

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