Dynamic Spectrum Access and Management in Cognitive Radio Networks

Are you involved in designing the next generation of wireless networks? With spectrum becoming an ever scarcer resource, it is critical that new systems utilize all available frequency bands as efficiently as possible. The revolutionary technology presented in this book will be at the cutting edge of future wireless communications.

Dynamic Spectrum Access and Management in Cognitive Radio Networks provides you with an all-inclusive introduction to this emerging technology, outlining the fundamentals of cognitive radio-based wireless communication and networking, spectrum sharing models, and the requirements for dynamic spectrum access. In addition to the different techniques and their applications in designing dynamic spectrum access methods, you'll also find state-of-the-art dynamic spectrum access schemes, including classifications of the different schemes and the technical details of each scheme. This is a perfect introduction for graduate students and researchers, as well as a useful self-study guide for practitioners.

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Preface

Frequency spectrum is a limited resource for wireless communications and may become congested owing to a need to accommodate the diverse types of air interface used in next generation wireless networks. To meet these growing demands, the Federal Communications Commission (FCC) has expanded the use of the unlicensed spectral band. However, since traditional wireless communications systems also utilize the frequency bands allocated by the FCC in a static manner, they lack adaptability. Also, many studies show that while some frequency bands in the spectrum are heavily used, other bands are largely unoccupied most of time. These potential spectrum holes result in the under-utilization of available frequency bands.

The concepts of software-defined radio and cognitive radio have been recently introduced to enhance the efficiency of frequency spectrum usage in next generation wireless and mobile computing systems. Software radio improves the capability of a wireless transceiver by using embedded software to enable it to operate in multiple frequency bands using multiple transmission protocols. Cognitive ratio, which can be implemented through software-defined radio, is able to observe, learn, optimize, and intelligently adapt to achieve optimal frequency band usage. Through dynamic spectrum access, a cognitive wireless node is able to adaptively and dynamically transmit and receive data in a changing radio environment. Therefore, techniques for channel measurement, learning, and optimization are crucial in designing dynamic spectrum access schemes for cognitive radio under different communication requirements.

In fact, cognitive radio based on dynamic spectrum access has emerged as a new design paradigm for next generation wireless networks. Cognitive radio aims at maximizing the utilization of the limited radio bandwidth while accommodating the increasing number of services and applications in wireless networks. The driving force behind this cognitive radio technology is the new spectrum licensing paradigm initiated by the FCC, which will be more flexible to allow unlicensed (or secondary) users to access the spectrum as long as the licensed (or primary) users are not interfered with. This new spectrum licensing paradigm will improve the utilization of the frequency spectrum and enhance the performance of wireless systems. Dynamic spectrum access (DSA) or opportunistic spectrum access (OSA) is the key approach in a cognitive radio network which is adopted by a cognitive radio user (i.e. an unlicensed user) to access the radio spectrum opportunistically. Development of dynamic spectrum access-based cognitive radio technology has to deal with technical and practical considerations as well as regulatory requirements. Therefore, there is increasing interest in this technology from researchers in both academia and industry, and engineers in the wireless industry, as well as from spectrum policy makers.

Design, analysis, and optimization of dynamic spectrum access require multidisciplinary knowledge, namely, knowledge of wireless communication and networking, signal processing, artificial intelligence (e.g. for learning), decision theory, optimization, and economic theory. A comprehensive introduction to the dynamic spectrum access and spectrum management problem in a cognitive radio network therefore needs to cover the basic concepts/theories for designing dynamic spectrum access methods as well as state-of-the-art of dynamic spectrum access and management methods.

This book provides a comprehensive treatment of the dynamic spectrum access and spectrum management problem in cognitive radio networks. The topics covered include the following: introduction to cognitive radio and the basic concepts of dynamic spectrum access; the analysis, design, and optimization of dynamic spectrum access techniques for cognitive radio; and state-of-the-art of dynamic spectrum access techniques. The key features of this book are as follows:

- a unified view of dynamic spectrum access for cognitive radio networks,
- coverage of a wide range of techniques for design, analysis, and optimization of dynamic spectrum access for cognitive radio networks,
- comprehensive treatment of state-of-the-art dynamic spectrum access techniques, and
- outlining the key research issues related to dynamic spectrum access.

The book is divided into three parts: Part I (Introduction), Part II (Techniques for design, analysis, and optimization of dynamic spectrum access and management), and Part III (Dynamic spectrum access and management). Part I comprises Chapters 1 and 2, which provide an introduction to the different wireless technologies and cognitive radio networks. The topics covered include the basics of cellular wireless, wireless local area network (WLAN), wireless metropolitan area network (WMAN), wireless personal area network (WPAN), wireless regional area network (WRAN) technology and related standards; the basic components, features, and potential applications of cognitive radio; an introduction to dynamic spectrum access; the motivations for cognitive radio-based wireless access technology; and the research issues in the different layers of the protocol stack for a cognitive radio network.

In Part II, different techniques which can be applied to the problem of the design, analysis, and optimization of dynamic spectrum access mechanisms in cognitive radio networks are introduced. In Chapter 3, the signal processing techniques (e.g. techniques for parameter estimation, filtering, and prediction) which are required for a wireless node to observe and gain knowledge of the ambient radio environment in order to access the radio spectrum dynamically are described. Optimization techniques, which are useful to obtain the optimal dynamic spectrum management scheme, are discussed in Chapter 4. Major variations of optimization techniques (e.g. unconstrained and constrained optimization, non-linear optimization, combinatorial optimization) are presented. Also, stochastic optimization based on dynamic programming, the Markov decision process (MDP), and stochastic programming for dynamic spectrum access in a random radio environment are discussed. In Chapter 5, game theory techniques are discussed in the context of designing dynamic spectrum access methods. Game theory is an attractive tool to model the dynamic spectrum sharing problem in a cognitive wireless network. The basics of different game theory models, namely, non-cooperative, repeated, cooperative (i.e. bargaining and coalition), and evolutionary game models are presented. Intelligent algorithms (i.e. learning techniques) are fundamental to cognitive radio design, and provide the ability to observe, learn, plan, and optimize the decision of dynamic spectrum access in a cognitive radio network. An introduction to different machine learning techniques including supervised learning, unsupervised learning, and reinforcement learning is provided in Chapter 6. Example applications of these techniques are discussed in the context of cognitive radio. Intelligent techniques based on genetic algorithms and fuzzy control are also discussed.

Part III deals with the modeling, design, and analysis of dynamic spectrum access and management schemes in cognitive radio networks. In Chapter 7, different models of spectrum access/sharing are discussed. Different approaches for spectrum sensing, which is a key component of dynamic spectrum access, are reviewed. A comprehensive review of the different medium access control (MAC) protocols developed for dynamic spectrum access is presented. Dynamic spectrum access and management architectures can be either centralized or distributed. In the centralized approach, a central controller collects information about the radio environment and controls the spectrum access by cognitive radio users. In Chapter 8, different schemes for centralized dynamic spectrum access are reviewed. Chapter 8 also introduces the concept of spectrum auction, which requires a centralized auctioneer for dynamic spectrum access and management. If there is no central controller available in a cognitive radio network, the cognitive radio users have to make their spectrum access decisions independently in a distributed manner. Chapter 9 introduces the concept of distributed dynamic spectrum access. Two major approaches to distributed dynamic spectrum access, namely, the cooperative and the non-cooperative approach are discussed. Chapter 10 deals with the application of learning algorithms in distributed dynamic spectrum access. The signaling protocols required to support distributed spectrum access are also reviewed. While dynamic spectrum access and management can be designed by considering only the technical issues, the economic issues are also important, especially under the new spectrum licensing paradigm. Chapters 11 and 12 address the economic aspects of spectrum sharing and management in a cognitive radio network. Chapter 11 introduces the concept of spectrum trading and reviews the different spectrum trading schemes. Through spectrum trading, the licensed users (or primary service provider) are able to sell a portion of the unused spectrum to the unlicensed users (or secondary service provider). The basic economic theories which can be used in dynamic spectrum access are reviewed. Chapter 12 provides an extensive review of economics-inspired dynamic spectrum access and management models. The first two models are based on competitive dynamic spectrum access and pricing. The concept of *collusion* among cognitive radio users in the context of spectrum trading is discussed. A spectrum trading model for IEEE 802.22-based wireless regional area networks (WRANs) is presented.

To use this book, if the reader is familiar with wireless technologies and the concept of cognitive radio, the first chapter can be skipped. Also, if the reader is an experienced researcher, some of the chapters in Part II can also be skipped. Since each chapter is quite independent, skipping any chapter will not affect following the rest of the book.

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