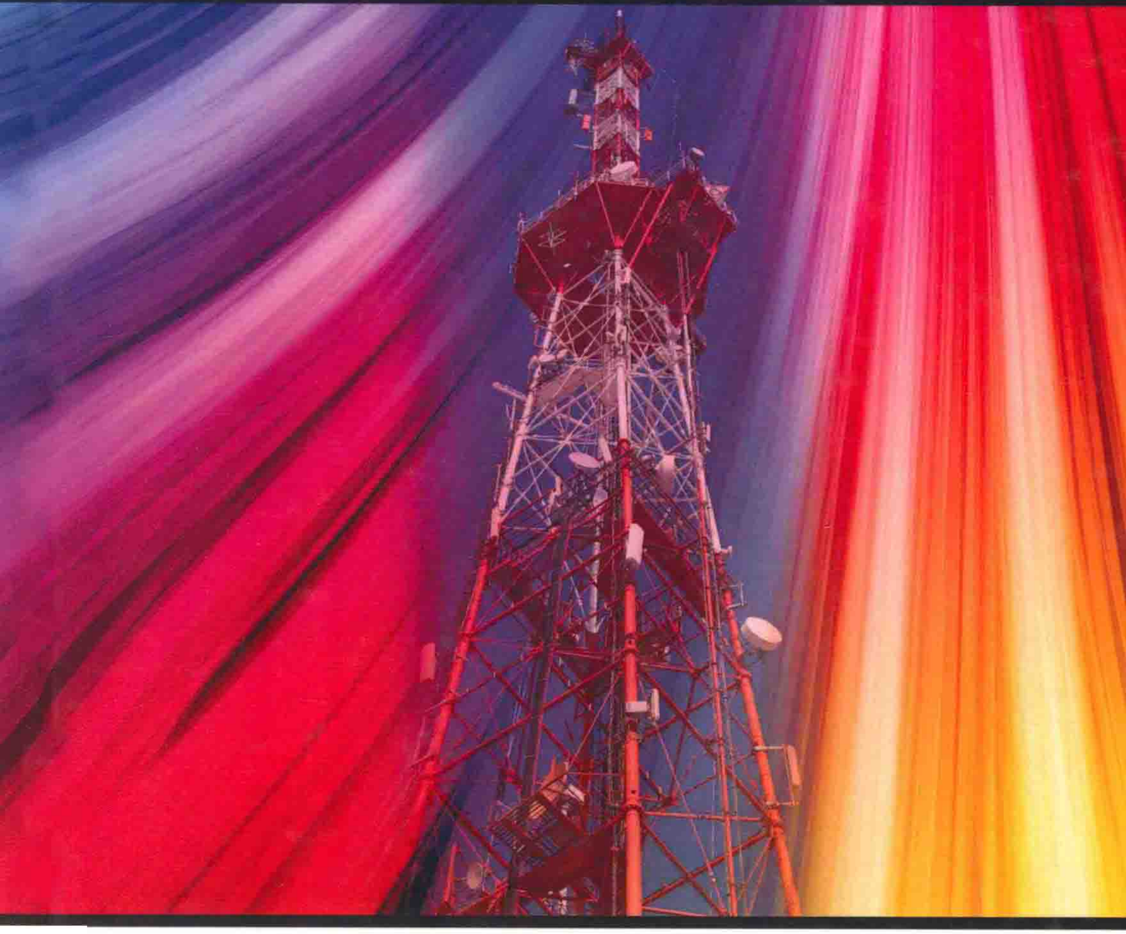
TV White Space Spectrum Technologies

Regulations, Standards, and Applications



Edited by
Rashid A. Saeed and Stephen J. Shellhammer

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Rashid has published and is responsible for over 70 research papers, tutorials, talks, and book chapters on the topic of UWB, cognitive radio, and radio resources management. He was awarded two US patents and has filed for eight more. Rashid is a certified WiMAX engineer (RF and core network) and is a Six Sigma–certified Black Belt, based on DMAIC++ from Motorola University. He is one of the contributors of IEEE-WCET wireless certification in its earlier stages, and is a senior member of the IEEE, IEM Malaysia, and Sigma Xi.

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Introduction

Rashid A. Saeed and Stephen J. Shellhammer

Overview

The need for additional spectrum to provide wireless services has been growing at an accelerating pace. Smartphone use has exploded, and meeting the demand for wireless broadband services is a challenge. One of the main issues is the scarcity of spectrum to support these wireless services. Cognitive radio (CR) is a promising new technology for enabling access to additional spectrum that is so badly needed. A number of conferences focusing on cognitive radio have emerged in the past few years, and there has also been an increase in the number of publications focusing on cognitive radio, including a number of recent cognitive radio books published [1–14]. However, up till now there has not been a book published with a specific focus on cognitive radio in the TV white space (TVWS). This volume covers a broad range of topics on the TV white space wireless networks.

TVWS—Broadcast Television to Wireless Broadband

TV white space is the portion of the TV bands that is unused by licensed services. There are many TV channels in very high frequency (VHF) and ultrahigh frequency (UHF) TV bands. In some geographic regions the utilization of these TV channels is high, while in other regions many of the channels are unused. Regulatory agencies, like the Federal Communication Commission (FCC) in the United States, have been developing regulations to allow wireless networks to obtain access to these unused channels while ensuring that these wireless networks not cause harmful interference to the licensed services in the TV bands. The set of unused TV channels, referred to as TV white space, can change based on geographic location and on time.

Since the TV white space spectrum, in both the VHF and UHF band, is below 1GHz it will provide much better RF propagation than the systems deployed in the Industrial, Scientific and Medical (ISM) bands, allowing for a reliable, cost-effective, and better coverage in rural areas and metropolitan applications, such as intelligent transportation, emergency and public safety, and smart grid.

Why TVWS is Unique

Operation in the TV white space is conditioned on the devices not causing harmful interference to the licensed services in the TV bands. Cognitive radio technology is proposed in TV white space to ensure that the TV white space devices do not cause harmful interference to the incumbent services operating in the occupied TV channels.

There are several cognitive radio technologies that have been developed to ensure this protection of licensed services. The first cognitive radio technology is actually a combination of two technologies: geo-location positioning and a database of incumbent systems. Geo-location positioning is the ability of a TV white space device to know its location in terms of latitude and longitude. An example of a geo-location positioning technology is a global positioning system (GPS) receiver. The TV white space database is a database which stores information about all the licensed services in the TV bands. For example, the database stores the location of a TV broadcast station, its channel of operation, and its transmit power. From this information it can calculate a geographic region in which TV receivers can receive the TV broadcast signal and are to be protected from harmful interference. The TV white space database provides information to the TV white space devices as to which channels they can utilize in their known location. In some cases, like for fixed outdoor systems that are professionally installed, the GPS system may not be required, because the fixed system which has been professionally installed is at a registered location, which has been certified by the professional installer.

The second cognitive radio technology used to protect incumbent systems, referred to in the literature as *spectrum sensing,* is a technology embedded in the TV white space device that makes measurements of the radio frequency (RF) TV channels. From those RF measurements. it determines which channels are occupied by incumbent systems and which are unoccupied and are hence TV white space.

In the first case the cognitive radio technology is split between the TV white space device (geo-location) and an external entity (TV white space database). In the second case the cognitive radio technology (spectrum sensing) is embedded entirely within the TV white space device. Given that it is becoming difficult for regulators to free up spectrum that is fully cleared of incumbent systems, it is likely that these cognitive radio technologies and other cognitive radio technologies will be used widely in the future to allow commercial wireless systems to share spectrum with incumbent systems. The TV white space represents the first example of what will likely become a popular regulatory structure in the future.

Book Outline

This book contains contributions by many coauthors from the wireless industry, standards developers, and academia in TV white space, dynamic spectrum access, and cognitive radio fields. It provides an overview of many topics relevant to TV white space. The book is organized in four sections. **Section I** focuses on regulations, spectrum policies, channelization and pre-system requirements. This must be the starting point because, without regulatory rules that permit wireless operation in the TV white space, no networks or devices can be built or deployed in the band. Chapters on regulation and policy cover wide regions from around the world, from the United States to Europe, Australia, Japan, and Singapore. **Section II** focuses on TV white space standards efforts in different standard-developing organizations (SDOs), with emphasis on the IEEE 802.22 wireless regional area network (WRAN) standard. **Section III** addresses coexistence of the TV white space devices with licensed services and also coexistence of the different networks of TV white space devices. The chapters in this section describe coexistence techniques between all potential standards, technologies, devices, and service providers. In this section there are two chapters on spectrum sensing looking to strengthen and enrich sensing research, as the FCC did not consider sensing mature enough to be adopted as mandatory requirements in their regulations. This part also presents database as a reliable scheme for coexistence. **Section IV** discusses some other important aspects in TV white space, including spectrum allocation, use cases, and security. The four sections are discussed below in detail.

Section I

Chapter 1 provides a summary of TV white space regulations around the world. There is a detailed study of the United States Federal Communication Commission (FCC) rules because the United States was the first country to develop such regulations and because the rules evolved over many years. The chapter begins with a history of the regulations beginning with the Spectrum Policy Task Force in 2002, then moving on to the proposed regulations which resulted in significant industry involvement and feedback to the FCC, and ending with a summary of the final rules that were issued in 2010. After going over the FCC regulations, the chapter summarizes the ongoing development of TV white space regulations in other regions of the globe.

In Europe the Conference on Postal and Telecommunications Administrations (CEPT) has begun studying different possible TV white space regulations. The European Communication Committee (ECC), within CEPT, has established a project called SE43 on cognitive radio systems in the TV white space. A summary of that SE43 technical report is provided in Chapter 1. The European rules share similarities with those in the United States, but are different in a number of ways. In addition, the final regulations must be provided by the individual European member states, which could each be a little different. The Office of Communication (Ofcom) in the United Kingdom has been developing regulations. It is not uncommon for the United Kingdom to be able to develop regulations before other European member states, because being an island eliminates the border issues that other member states must address. The chapter also provides a summary of the regulatory activities in Canada, where there has been a focus on rural broadband systems to provide service to rural areas that may be currently unserved or underserved. The chapter concludes by discussing the activities in several Asian countries, including Japan, Korea, and Singapore.

Chapter 2 takes a look at how establishing TV white space regulations now will potentially impact future regulations. The authors from Australia analyze these issues in their country, but those same issues could equally well apply to other countries. The authors bring up the issue of a future Digital Dividend 2, in which some of the current TV broadcast spectrum is reallocated to licensed wireless telecommunications. If unlicensed TV white space devices are deployed today in the unused TV channels, what will be the effect on future licensed telecommunication systems? These TV white space devices will be designed to share spectrum with broadcast TV systems, but will they be able to adapt to Digital Dividend 2 when licensed telecommunication systems are deployed in the band? The authors make comparisons of the wireless microphone systems that have been allowed to operate in unused TV channels for many years and the newer TV white space devices that will be permitted to operate in those unused channels. The chapter provides background on TV white space concepts as well as an overview of Australian spectrum regulations. The authors discuss the impact of TV white space devices on the potential Digital Dividend 2, in which a portion of the current TV broadcast spectrum is reallocated for cellular telecommunication networks.

Chapter 3 discusses the impact of the TV white space regulations on the system requirements of the TV white space devices and networks (i.e., maximum antenna heights used in the system, operation of a database, spectrum masks, maximum transmitted power, etc.). This chapter describes the TV white space database requirement that must be met to protect the incumbent systems in the TV bands. A summary of the device requirements is also provided.

Chapter 4 provides an analysis of the quantity of TV white space in the United States. One of the questions that comes up when considering use of the TV white space is "how much spectrum is there?" The number of available channels depends on which type of devices one is considering. One can set up a fixed network consisting entirely of fixed TV white space devices. Similarly, one can set up a portable network consisting entirely of portable TV white space devices. And finally, one can set up a network consisting of a combination of both fixed and portable devices. The number of TV white space channels available depends on which type of network one is considering. This chapter analyzes the FCC regulations and applies them to databases of standard-power and low-power TV broadcast stations.

Chapter 5 evaluates the potential for TV white space operation in Europe. It provides background material on digital terrestrial TV in Europe, describing the digital video broadcasting project for terrestrial reception (DVB-T) deployment in Europe. The chapter gives an overview of the CEPT ECC SE43 project on cognitive radio in the TV white space, as well as an overview of the European Telecommunications Standards Institute (ETSI) project on reconfigurable radio systems. Then the authors develop a case study of TV white space in Finland, calculating the number of potential TV white space channels for different regions in Finland. The chapter ends by applying a model of innovation growth to the TV white space and makes predictions about the level of TV white space usage in the future.

Section II

Chapter 6 covers standards for physical (PHY) layer and medium access control (MAC) layers, operating in the TV white space. The first standard considered is the ECMA-392 standard for wireless networking of personal/portable devices in the TV white space. This standard was developed specifically for the TV white space and supports both master–slave and peer-to-peer topologies. The MAC and PHY layers have been designed to support wireless delivery of high-definition video within the home. The standard supports both geo-location/database and spectrum sensing for protection of incumbent systems. Another standard that specifically targets the TV white space is IEEE 802.22, which was recently published by the IEEE. This is a standard for wireless regional area networks (WRANs). The standard was originally derived from IEEE 802.16e, but has been enhanced to support TV white space operation. The PHY layer has been modified to provide support for longer-range operation. In addition to the traditional data and management planes in wireless network architecture, IEEE 802.22 has added a cognitive plane for the various cognitive radio technologies. The standard supports geo-location and database access for protection of incumbent systems. The standard also provides support for spectrum sensing and includes an informative annex on various spectrum sensing techniques that were evaluated by the IEEE 802.22 working group. Finally, the standard provides several techniques for neighboring WRAN cells to coexist. The next standard project that is considered IEEE 802.11af, which is an amendment to the popular IEEE 802.11 wireless local area network standard, often referred to by its market name Wi-Fi. This project began in 2010 and is still under development. This amendment makes enhancements to the MAC and PHY layer for operation in the TV white space. The PHY layer is an orthogonal frequency domain multiplex (OFDM) PHY design with support for multiple bandwidths, which are based on earlier amendments. The PHY layer is expected to be a clock-scaled version of an earlier OFDM PHY to fit in the TV white space channels, which is a narrow bandwidth that the PHY layers used in the ISM bands. The final MAC/PHY that is considered is an ad hoc committee within the IEEE Standards Coordinating Committee 41 (SCC41) which is looking into starting a new MAC/PHY project for the TV white space.

Chapter 7 discusses TVWS coexistence and dynamic spectrum access (DSA) standardization activities at upper layers. This includes IEEE 802.19, IEEE 1900.4, and ETSI. The IEEE 802.19 project is developing a standard that will utilize the location awareness of the TV white space devices to improve coexistence between different wireless networks, even if they are designed according to different standards, while IEEE 1900.4 WG is developing standards specifying management architectures enabling distributed decision making for optimized radio resource usage in heterogeneous wireless access networks. ESTI activities are quite broad and cover CR and software defined radio (SDR) architectures and related application programming interfaces (APIs).

Chapter 8 discusses system-level analysis of OFDMA-based networks in TV white spaces with emphasis on IEEE 802.22 as a case study. The chapter develops a theoretical framework for throughput evaluation in opportunistic spectrum access (OSA) systems. The chapter also describes NS-2 simulation and implementation for IEEE 802.22 based on the OS-OFDMA scheme. Results show the impact of temporal and/or spatial wireless microphone operation on IEEE 802.22 performance.

Chapter 9 presents spectrum sharing in inter-network using an IEEE 802.22 scenario. The chapter discusses a distributed, message-based, cooperative, and real-time spectrum sharing concept called on-demand spectrum contention (ODSC) that is used in IEEE 802.22. The ODSC protocol is described, and beacon period framing (BPF) protocol that enables reliable, efficient, and scalable inter-network communications is also discussed. Other interesting inter-network discussions like dedicated or in-band radio frequency issues and backhaul-based or over-the-air inter-network communications are highlighted as well.

Section III

Chapter 10 presents various spectrum sensing aspects and issues related to TV white space. Special attention has been paid to sensing in ongoing TV white space standards including, for example, IEEE 802.22 and the IEEE 802.11af. Throughout the chapter, many TVWS scenarios were studied and elaborated. The chapter shows that sensing is crucial for devices that do not register in any geo-location database, and how spectrum sensing can be used by service providers to improve their systems.

Chapter 11 explores energy detection-based distributed spectrum sensing (DSS), where three distributed sensing schemes are discussed: cooperative sensing, collaborative sensing, and selective sensing. In distributed sensing, multiple sensors make RF measurements and share their local measurement results and then, by combining measurement results, form multiple independent sensors from which an improved global spectrum sensing result can be obtained. The chapter provides a theoretical analysis based on analytical models providing results for the probability of detection in Rayleigh fading channel, showing the improvement in sensing performance, possible by using distributed spectrum sensing.

Chapter 12 presents protection of incumbent systems in the TV white space by using a white space database, as well as spectrum sensing. As the coexistence issues with the incumbent are described, the chapter discusses many of the aspects that must be considered in a TV white space database. These aspects include cooperative databases, synchronization between databases, access security, and authentication. Since in some cases the database may not be accessible or updated with current incumbent information, this may lead to reduced frequency agility and spectrum utilization efficiency. The chapter introduces a new system architecture, which is based on both spectrum sensing and database access.

Section IV

Chapter 13 describes acquisition principles for acquiring spectrum that lead to efficient TVWS spectrum allocation. The chapter reviews the roles of a number of elements that may lead to reliable and efficient allocation of the TV white spaces. The chapter begins with a discussion of the various approaches to spectrum regulation: command and control, spectrum commons, and market-based approach. Among the approaches to spectrum policy that is considered in this chapter is having an intermediary operating between the TV white space networks and the incumbent systems. The chapter provides a number of motivations for the need of intermediaries to facilitate the functioning of the TVWS systems from a market perspective and presents cognition as an enabling technology. The chapter then provides a summary of many of the factors that must be considered in the protection of the incumbent systems. The realization of many of these factors will ultimately be embedded in the TV white space database. The chapter ends with a description of several methods of making spectrum available for TV white space devices. These methods can be divided into device-centric approaches like spectrum sensing, and network-centric approaches like database access.

Chapter 14, which is a follow-up from Chapter 13 by the same authors, continues discussing elements of efficient TV white space allocation with a focus on business models. Two business models are considered: TV White Space Information Provision and Wireless Service Provision in the TV white space. In the first model, the spectrum context broker sells or provides reliable spectrum context to potential TV white space devices. The model combines all the roles related to spectrum context collection, processing and dissemination. In the second model, an operator acquires reliable spectrum context information from the broker and provides wireless services to the end user.

Chapter 15 provides an overview of several application use cases in TV white space. Many of the use cases are similar to wireless use cases in other frequency bands. However, TV white space has its unique characteristics that impact the types of use cases that are a good fit for this spectrum. One of the characteristics of the TV white space spectrum is its low frequency, which leads to long-range operation. Another characteristic is the fact that it is a license-exempt frequency band, which makes it possible to deploy devices and networks without having to purchase the rights to the spectrum access. Some of the potential use cases introduced in this chapter include large area connectivity, utility grid networks, transportation and logistics, mobile connectivity, high speed vehicle broadband access, office and home networks, and emergency and public safety.

Chapter 16 explains the security and privacy issues that may threaten TV white space applications. The chapter characterizes security and privacy in to three pairs of antagonistic parameters: the first one is associated with all wireless communications, while the other two are new and unique to TVWS technology. The first pair of parameters is related to access to the system and deals with denial of access when it should be granted, and granting spectrum access when it should not be, thereby causing interference to an incumbent system. The second pair of parameters is related to protection of incumbent systems and is concerned with providing access when it should be provided, and not granting spectrum access when it should be granted, resulting in a device or a network of devices unable to utilize spectrum to which they should have access. The third pair of parameters concerns accountability and privacy. The chapter also discusses a set of privacy threats that are inherent with the TVWS database server. The authors also believe that the privacy and security solution space is complicated by the political interactions of large commercial players (e.g., TV broadcasters and wireless MIC vendors) with significant financial considerations.

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