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White space: Definitional perspectives and their role in exploiting spectrum opportunities

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ABSTRACT

The U.S. Federal Communications Commission (FCC) defines white space as the channels that are unused at a specific location or time. For futuristic cognitive radio (CR) based applications and communication networks, white space detection plays an important role. In fact, the proper white space understanding is a prerequisite for effective communication in support of a wide range of information technology systems. Moreover, by clearly defining the white space, the business and technical scenarios for white space usage can be clearly defined and their implementation will be simplified. Also, the decisions of regulatory bodies and telecommunications policy makers for auctions of particular spectrum bands can be facilitated by a thorough white space understanding. White space detection is a critical aspect of Dynamic Spectrum Access (DSA) which ultimately can help in overcoming bandwidth shortages. A major portion of the DSA research to date has been limited to the dimensions of time, frequency, and geographical location while neglecting other perspectives for the detection of white spaces. Generally, what exactly is a white space and how do white spaces differ in various modern contexts of wireless networks? This paper strives to answer these questions by reviewing the conventional white space definitions and exploring advanced perspectives on white spaces that can be used for CR communications. We propose a novel classification of white spaces based on the combination of three perspectives, namely signal dimension, licence, and transmission strategy, and outline open areas for future research on exploiting white spaces for CR communication.

1. Introduction

Radio terminals have traditionally been designed to operate on a prescribed (allocated) set of frequencies and exclusively access these frequencies, i.e., the frequency spectrum space, when they have some data to transmit. When the radio terminals are idle or partially utilize spectral resources, some portions of the allocated frequency spectrum are left unused or underutilized. Measurements indicate that traditional radio terminals lead to spectrum occupancy probabilities varying over time between 15% and 85% at a given geographical location (Akyildiz, Lee, Vuran, & Mohanty, 2006; Masonta, Mzyece, & Ntlatlapa, 2013; Shin, Kim, Min, & Kumar, 2010). From a technical viewpoint, the unused and underutilized frequency spectrum spaces are referred to as *white spaces* (Webb, 2012). Efficient utilization of these white spaces has the potential to

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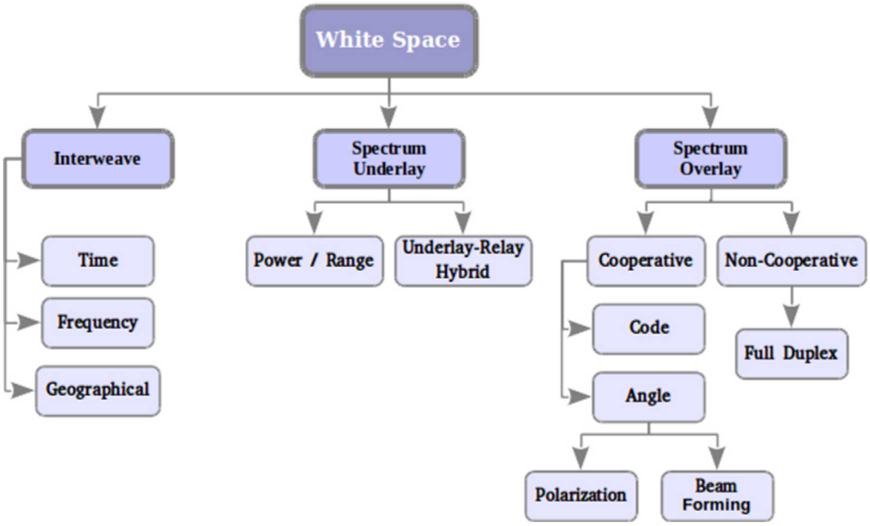

Fig. 1. Taxonomy of white spaces: The spectrum usage of cognitive radio (CR) users can be interwoven, underlaid, or overlayed with the spectrum usage by primary users (PUs).

mitigate spectrum shortages. Specifically, new approaches that either fully utilize the spectral resources or exploit white spaces without affecting current users can help us to improve the spectrum utilization.

A promising solution for exploiting these white spaces is to employ Dynamic Spectrum Access (DSA) techniques (Lu, Ping, Niyato, & Hossain, 2014; Zhao & Sadler, 2007). DSA techniques are the enabling technology of Cognitive Radio (CR) (Shin et al., 2010). Among several CR attributes, the sensing function is of critical importance—it senses the activity patterns of present users and determines potential white spaces for exploitation (Akyildiz, Won-Yeol, & Chowdhury, 2009b, 2011; Kocks et al., 2012; Yucek & Arslan, 2009). However, the potential of sensing white spaces for communication may presently be substantially underestimated due to the current narrow definitions of white spaces, which can be broadened as outlined in this paper.

In particular, the ongoing research on CR communication mainly focuses on the detection of white spaces in idle licensed frequency bands and within only a few signal space dimensions, specifically the dimensions representing time, frequency, and geographic (spatial) location. However, white spaces can be viewed more broadly: White spaces:

- do not necessarily exist only in an idle band,
- are not necessarily limited to specific dimensions of the signal space, and
- are not necessarily limited to licensed frequency bands.

The limiting narrow views of sensing of white spaces are mainly due to current definitions of white space, which considerably restrict the potential of CR communication. However, white space can be viewed from several different perspectives. These different perspectives need to be distinctly defined and jointly considered, as only considering a single definition may limit the potential of CR communication. Hence, it is of paramount importance to understand and differentiate various perspectives on white spaces. Fig. 1 illustrates a taxonomy of white spaces based on current research trends on the CR paradigm. Clarifying white space definitions may aid in overcoming current hurdles while facilitating wireless communication innovation.

This paper attempts to clarify the definitions of white space by differentiating the various definitional perspectives. We first provide background in Section 2 and then review current definitions and their scope in Section 3. Subsequently, we discuss the existence of white spaces based on current technological trends, i.e., white space in the interweave, underlay, and overlay paradigms in Sections 4, 5, and 6, respectively. Furthermore, we discuss white space from the licensing perspective is Section 7. Then, we provide a brief discussion of current issues and future possibilities for exploiting white spaces in future wireless systems in Section 8. We conclude the paper in Section 9.

2. Background

From a technical perspective, the radio spectrum is the part of the electromagnetic spectrum that corresponds to the wavelengths (and corresponding frequencies) used for radio communications. These wavelengths are used by a wide range of applications and are separated into chunks, i.e., corresponding frequency bands ranging from 9 KHz to 3000 GHz (Marcus,

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