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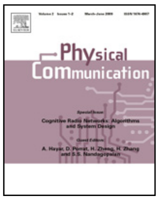

Full length article

Analysis of mobility impact on interference in cognitive radio networks[☆]

Ali Rıza Ekti[a,*], Serhan Yarkan[b], Khalid A. Qaraqe[c], Erchin Serpedin[a], Octavia A. Dobre[d]

[a] Department of Electrical and Computer Engineering, Texas A&M University, College Station, TX, 77843–3128, United States
[b] Department of Electrical and Electronics Engineering, Istanbul Commerce University, Küçükyalı, İstanbul, 34840, Turkiye
[c] Department of Electrical and Computer Engineering, Texas A&M University at Qatar, Education City, 23874, Doha, Qatar
[d] Faculty of Engineering & Applied Science, Memorial University of Newfoundland, St. John's, NL, A1B 3X5, Canada

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ABSTRACT

Cognitive radio (CR) technology seems to be a promising candidate for solving the radio frequency (RF) spectrum occupancy problem. CRs strive to utilize the white holes in the RF spectrum in an opportunistic manner. Because interference is an inherent and a very critical design parameter for all sorts of wireless communication systems, many of the recently emerging wireless technologies prefer smaller size coverage with reduced transmit power in order to decrease interference. Prominent examples of short-range communication systems trying to achieve low interference power levels are CR relays in CR networks and femtocells in next generation wireless networks (NGWNs). It is clear that a comprehensive interference model including mobility is essential especially in elaborating the performance of such short-range communication scenarios. Therefore, in this study, a physical layer interference model in a mobile radio communication environment is investigated by taking into account all of the basic propagation mechanisms such as large- and small-scale fading under a generic single primary user (PU) and single secondary user (SU) scenario. Both one-dimensional (1D) and two-dimensional (2D) random walk models are incorporated into the physical layer signal model. The analysis and corresponding numerical results are given along with the relevant discussions.

1. Introduction

As wireless communications pervade daily life, many of the ever increasing demands should be met simultaneously. Some of those demands are high performance, improved capacity, better coverage, quality of service (QoS), energy and cost efficiency, and reduced power consumption. Cognitive radio (CR) systems are expected to tackle these demands by applying advanced signal processing techniques [1–5]. Even though there is no formal definition of CR in the literature, a CR is a wireless device which can be aware of, learn about, and adapt to its surrounding environment [1]. The environment of a CR may include radio frequency (RF) spectrum, user behavior, transmission characteristics and parameters, multi-access interference, and so on [6]. Among all of these, multi-access interference has gained slightly more importance since it degrades the overall wireless communication system performance. This characteristic nature of interference becomes a vital design issue especially in next generation wireless networks (NGWNs) since frequency reuse of one (FRO) is the prominent deployment option. Therefore, it is easy to conclude that modeling and predicting the behavior of future interference levels are two essential tasks for both CRs and NGWNs.

Interference behavior is affected mainly by the following four factors: (F.i) environment, (F.ii) network topology/structure, (F.iii) mobility, and (F.iv) traffic type. Measurement results available in the literature illustrate that different environments affect the wireless signals (therefore,

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[*] Corresponding author.
E-mail addresses: arekti@tamu.edu (A.R. Ekti), syarkan@iticu.edu.tr (S. Yarkan), khalid.qaraqe@qatar.tamu.edu (K.A. Qaraqe), serpedin@ece.tamu.edu (E. Serpedin), odobre@mun.ca (O.A. Dobre).

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interference) in different ways [7]. Because each propagation environment presents different characteristics from the fading perspective [6, Table 3], interference in a propagation environment is expected to be different from that in another environment. One of the easiest ways for incorporating the impact of environment into the interference analysis is to use a simple path loss model with different path loss exponents corresponding to different environment types [8]. It is clear that such simplifications cannot provide a detailed description of the interference behavior. Therefore, more comprehensive models encompassing shadowing, small-scale fading, and their higher-order statistical characteristics are required.

In contrast to (F.i), (F.ii) refers to a more flexible factor since some properties such as network structure, topology, and deployment can be controlled and/or designed to some extent. From this point of view, the impact of (F.ii) on interference behavior changes with respect to the design options at hand. In traditional cellular systems, one of the most dominant sources of interference is co-channel interference (CCI). CCI is controlled by employing re-use of the frequencies in distant cells (large cluster sizes or re-use factors) at the expense of capacity degradation, such as in Global System for Mobile Communications (GSM) [7,9]. However, especially for NGWNs, FRO seems to be the most prominent deployment option for a general cellular layout, as it improves capacity. Note also that FRO bypasses the frequency planning stage in cellular design, which is a very expensive process. Nonetheless, FRO introduces significant CCI into the system especially for the terminals residing in the vicinity of the cell borders [10]. Similar to centralized and non-centralized schemes, interference behavior in a multi-hop network along with the multi-input multi-output (MIMO) option [11] is not the same as in the single-input single-output (SISO) option.

The impact of (F.iii) on interference behavior has more than one aspect. At the microscopic time scale, mobility causes drastic power level fluctuations in the received signal (i.e., interference) [7]. Femtocells constitute one of the best contemporary examples of such scenarios [12–15]. Since the radius of femtocells is noticeably small compared to large-scale networks, the fluctuations in the interference power levels will be drastic due to the mobility of user equipments (UEs). Femtocells are initially designed to operate in licensed spectrum; therefore, a possible RF spectrum scarcity can be expected. Refs. [16,17] proposed an efficient channel reuse approach for femtocells by using the sensing feature of CR. Using this approach, the uplink interference from a macrocell user to a femtocell user can be identified and the proper channel allocation can be established. On the other hand, at macroscopic time scales, the mobility behavior (or pattern) of the transceivers becomes dominant compared to each individual mobility pattern [18–20]. When coupled with multiple interfering sources, mobility behavior gains extra dimensions such as group-cluster behaviors as well as homogeneous–heterogeneous mobility patterns [21]. When the victim nodes are capable of acquiring information about the mobility behavior of interfering sources, they can improve their performances through the use of this knowledge.

For (F.iv), it is expected that depending on the content of the transmission, different interference scenarios will emerge. Experimental data reveal that voice traffic exhibits quasi-deterministic properties, whereas Internet traffic possesses self-similarity to some extent [20]. Other traffic types such as data, multimedia, and gaming demonstrate distinct stochastic characteristics implying various interference behaviors especially in NGWNs. In the presence of traffic knowledge, interference can be canceled and/or avoided by using interference scheduling techniques [5]. Sufficient statistics should be collected to obtain reliable characterization of the network traffic. Apart from (F.i)–(F.iv), there are some other factors affecting interference as well. Transmission frequency, weather/seasonal conditions and precipitation are just a few factors. For example, the presence of high pressure air can cause unintentional interference to other signals and eventually CCI can occur [22]. However, these factors are outside the scope of this study.

In light of the aforementioned discussions, the main contributions of this study can be itemized as follows: (I) a two-dimensional (2D) random walk mobility model is directly incorporated into the interfering fading signal at baseband and (II) all of the main propagation mechanisms (e.g., small- and large-scale fading) along with their higher-order statistical characteristics are taken into account in the signal model. Also, the impact of decorrelation distance on the interference is studied for different propagation environment schemes. The rest of the paper is organized as follows. In Section 2, the system model is presented. This is followed by the interference analysis of the system model, which is described in Section 3. Concluding remarks and further discussions are provided in Section 4. This is followed by Appendices A and B.

2. System model

Consider a primary user (PU)–secondary user (SU) simultaneous communication scenario where both transmitter (Tx)–receiver (Rx) pairs are in their close vicinity. In the SU network, assume that there is a secondary user transmitter (SU–Tx) (probably mobile) that is communicating with the secondary user receiver (SU–Rx). Both networks are assumed to operate on the same RF spectrum. Neither frequency division duplexing (FDD) nor time division duplexing (TDD) is allowed. Such scenarios are encountered generally in unlicensed (but regulated) RF bands such as industrial, scientific, and medical (ISM) band. In these scenarios, when a user transmits on one portion of the band of interest, a different user might be receiving on the same portion of the band at the same time, which leads to CCI. A general illustration of the set up considered in this study is depicted in Fig. 1.

In Fig. 1, it is assumed also that the separation between primary user receiver (PU–Rx) and SU–Tx is on the order of a couple of meters. With this assumption, femtocell scenarios for NGWNs can also be studied since coverage areas for the femtocells are approximately of this range [12]. SU–Tx exhibits low-speed mobility behavior similar to that of pedestrians. Such mobility behaviors will be modeled as a random walk for the sake of simplicity [23]. The justification for and details of the random walk assumption are