# Capacity Analysis in Multi-Radio Multi-Channel Cognitive Radio Networks: A Small World Perspective

**Xiaoxiong Zhong, Yang Qin, Li Li**

**Abstract** Cognitive radio (CR) has emerged as a promising technology to improve spectrum utilization. Capacity analysis is very useful in investigating the ultimate performance limits for wireless networks. Meanwhile, with increasing potential future applications for the CR systems, it is necessary to explore the limitations on their capacity in a dynamic spectrum access environment. However, due to spectrum sharing in cognitive radio networks (CRNs), the capacity of the secondary network (SRN) is much more difficult to analyze than that of traditional wireless networks. To overcome this difficulty, in this paper we introduce a novel solution based on small world model to analyze the capacity of SRN. First, we propose a new method of shortcut creation for CRNs, which is based on connectivity ratio. Also, a new channel assignment algorithm is proposed, which jointly considers the available time and transmission time of the channels. And then, we derive the capacity of SRN based on the small world model over multi-radio multi-channel (MRMC) environment. The simulation results show that our proposed scheme can obtain a higher capacity and smaller latency compared with traditional schemes in MRMC CRNs.

**Keywords** Capacity Analysis. Cognitive Radio Networks. Small World

## 1 Instroduction

The CR principle has introduced the idea to exploit spectrum holes (i.e., bands) which result from the proven underutilization of the electromagnetic spectrum by modern wireless communication and broadcasting technologies [1]. The exploitation of these holes can be accomplished by the notion of cognitive radio networks (CRNs). CRNs have emerged as a prominent solution to improve the efficiency of spectrum utilization and network capacity. In CRNs, secondary users (SUs) can exploit frequency bands when the primary users (PUs) do not occupy the bands. The objective of CRNs is to optimize the performance, e.g., the capacity of the SRN, without causing harmful effects on PUs. Existing research works on capacity of CRNs have mainly focused on improving the performance of the physical layer and media access control (MAC) [2]. These approaches can provide high capacity in single-hop topology, which are ineffective in multi-hop scenarios. For example, an optimized sensing threshold method may provide a higher capacity for a particular link. However, such a method may be inefficient when considering the average path length of a given multi-hop CRN.

Capacity analysis is very useful in investigating the ultimate performance limits for CR systems. Some efforts have been taken to improve the CR channel capacity through optimizing the lower-layer parameters [2-3]. In a CRN, the power control and the spectrum sensing are properly incorporated for the capacity optimization providing the PU's protection [4]. In [5], Jararian *et al.* studied a symmetric multiuser cognitive radio system and presented a lattice coding scheme which all the $L$ transmit-receive pairs can simultaneously communicate as if all cross channels were absent from the system. In [6], assuming a path loss shadow-fading model with multiple PUs and SUs, the system-level capacity of CRNs under an average interference power constraint has been investigated. Their results show that the uplink ergodic channel capacity of a CR-based central access network can be relatively large when the number of PUs is small. In [7], Li *et al.* analyzed the achievable throughput by using the characteristics of the single hop transport throughput of the SRN with outage constraints. In [8], capacity and delay scaling laws are introduced for cognitive radio ad hoc networks by capturing the impact of PU activity in dense and sparse PU deployment conditions.

The above mentioned proposals of capacity analysis are restricted to the link level, where only one CR transmitter opportunistically communicates with one CR receiver in the presence of a single or multiple primary receivers. They mainly focus on how to deal with the interference channel setting or power control. Taking end-to-end path into account, it is shown that cross layer design can maximize the sum commodity throughput through jointly optimize transmission power, constellation size, temporal schedule, and the corresponding optimal flow [9]. In [10], it is demonstrated that joint

---

School of Computer Science and Technology, Harbin Institute of Technology Shenzhen Graduate School, Shenzhen, 518055, People's Republic of China.
Xiaoxiong Zhong, e-mail: xixzhong@gmail.com
Yang Qin, e-mail: yqinsg@gmail.com
Li Li, e-mail:lili8503@aliyun.com