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# Modelling opportunistic spectrum renting in mobile cellular networks

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ABSTRACT

Spectrum pooling enables the opportunistic usage of licensed frequency bands for secondary users during the idle periods of primary users, which can be applied to relieve temporary bottlenecks in mobile cellular networks. In this paper, we provide an analytical framework for the performance evaluation of the interaction of multiple operators who cooperate and apply an opportunistic spectrum renting scheme. Based on our investigation, we provide a flexible and simple cooperation scheme when more than two operators are involved.



## 1. Introduction

The 2002 report of the Federal Communications Commission's (FCC) Spectrum Policy Task Force (Spectrum Policy Task Force, 2002) recommended a spectrum policy reform that is based on the flexible management of spectrum and liberalized/dynamic spectrum access. The idea of dynamic spectrum access is a radical approach compared to the current centralized spectrum management, that the exclusive access right of certain frequency bands is guaranteed to a specific operator. Since the release of the FCC report (Spectrum Policy Task Force, 2002), a quest for dynamic spectrum access technique to improve a spectrum efficiency has been intensively researched (see Spectrum Policy Task Force, 2002; Jabbari et al., 2010; Gandhi et al., 2008; Buddhikot, 2007; Zhao and Sadler, 2007; Peha, 2009; Weiss and Jondral, 2004; Talay and Altilar, 2013; Parvin et al., 2012 and references therein). Buddhikot (2007), Zhao and Sadler (2007), and Peha (2009) provided overviews and rationales concerning efficient spectrum sharing and access.

Although it is widely recognized that a spectrum management reform and dynamic spectrum access can provide a solution to the existing problem (i.e., the shortage of usable radio frequencies and the under-utilization of the licensed spectrum) (Spectrum Policy Task Force, 2002; Buddhikot, 2007; Zhao and Sadler, 2007), the application of dynamic and opportunistic spectrum access is rarely found in practice. A lot of issues (Spectrum Policy Task Force, 2002; Buddhikot, 2007; Zhao and Sadler, 2007; Weiss and Jondral, 2004) must be solved before the widespread application of opportunistic spectrum access.

Spectrum pooling is first proposed by Mitola (1999), which enables the secondary usage of the licensed frequency bands. The basic idea of the spectrum pooling is that secondary users may opportunistically utilize licensed frequency bands of primary users during the idle periods of primary users. Weiss and Jondral (2004) proposed a practical approach that allows the access of already licensed frequency bands without requiring any change to the licensed systems. The authors (Weiss and Jondral, 2004) described their solution for frequency-/time-division multiple access (FDMA/TDMA) based licensed systems. Furthermore, they (Weiss and Jondral, 2004) argued that spectrum pooling does not create a competition to existing and upcoming 2G and 3G mobile radio standards because a capacity shortage may happen due to a high demand in an area with limited frequency bands. In such cases, a specific operator can apply the spectrum pooling technique to enhance the grade of service for calls (i.e., to rent a free frequency band from another operator to serve incoming calls) (Tzeng and Huang, 2010; Tzeng, 2009; Do et al., 2012).

Some queueing models for spectrum renting were worked out (see Tzeng and Huang, 2010; Tzeng, 2009; Do et al., 2012). Tzeng (2009) and Tzeng and Huang (2010) assumed that user channels can be rented in one unit, which is not realistic because the separate blocks of user channels are defined in each frequency band and each block should be controlled by a single network operator. Do et al. (2012) presented the first queueing model to take into account this

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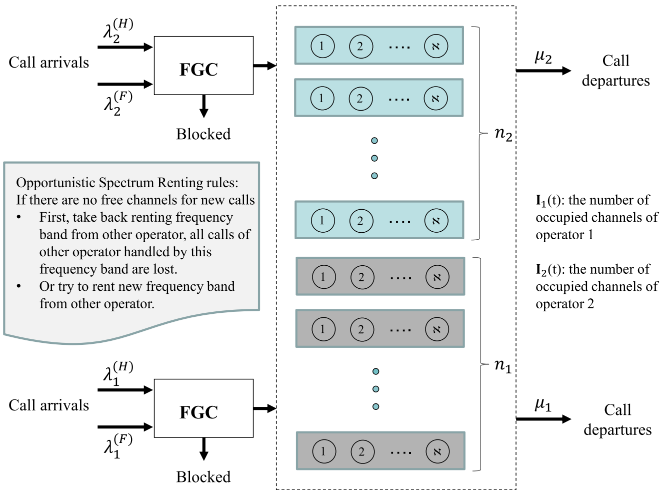


**Fig. 1.** Resource contention and spectrum renting in the case of two operators.

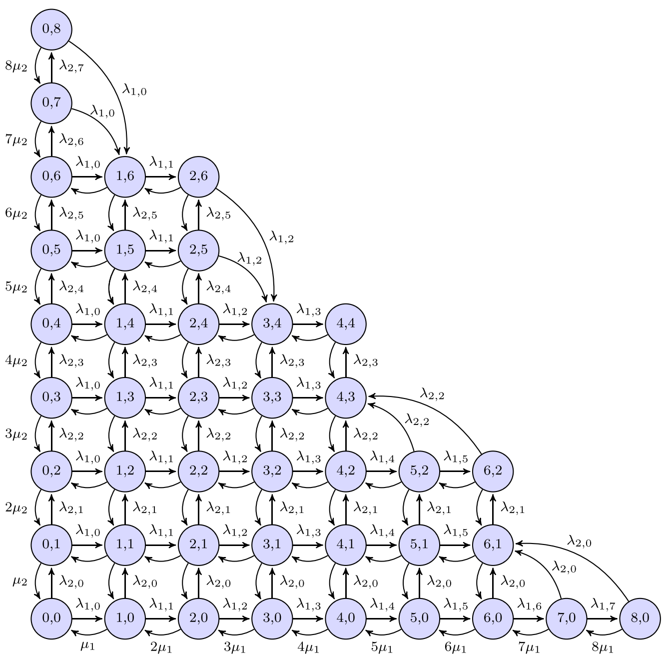

**Fig. 2.** Illustration of the state transition diagram.

technology aspect. Do et al. (2014) analyzed the retrial phenomenon with spectrum renting. However, they (Do et al., 2012, 2014) did not consider directly the interaction of operators.

In this paper, we provide an analytical framework for the performance evaluation of the interaction of multiple operators who cooperate and apply opportunistic spectrum renting in a specific area. For the ease of comprehension, we investigate a scenario where two operators apply an opportunistic spectrum pooling scheme in a specific area. We show that the proposed queueing model can accurately evaluate the performance of mobile cellular networks with call durations following the lognormal distribution. Based on our investigation, we provide a flexible and simple cooperation scheme when more than two operators are involved. The proposed scheme along with its simplicity can provide a good opportunity for operators to enhance a grade of service provisioned to subscribers, which could give an incentive for operators to cooperate together. To our best knowledge, this paper is the first work on modelling the interaction of multiple operators.

The rest of this paper is organized as follows. An overview on technical problems regarding spectrum pooling is provided in Section 2. A performance evaluation framework is presented in Section 3. The performance analysis and a numerical study in a case with two operators are presented in Sections 4 and 5, respectively. A general case when more than two operators are involved is discussed in Section 6. Finally, Section 7 concludes the paper.

## 2. A background on spectrum pooling

To realize a spectrum pooling system, several technical problems should be handled (Weiss and Jondral, 2004):

- First, the cooperating parties should be able to identify the idle spectral ranges for the secondary usage of the spectrum. To achieve this, a detection algorithm was proposed in Weiss et al. (2003a). Moreover, the diversity approach must be applied (Weiss et al., 2003a) to achieve the desired detection, which requires that all associated mobile terminals should perform spectral measurements.
- Second, the previously mentioned diversity approach involves an enormous signaling overhead which makes the system error-prone as interference will be occurred with the new licensed users. In Weiss et al. (2003b), a boosting protocol is proposed, which moves this signaling from the MAC layer to the physical layer.
- The third obstacle is the well known mutual interference problem. A possible solution of the mutual interference problem is the introduction of adaptive guard bands in the rental system. However, this method reduces the available bandwidth of the rental system. By all means, a trade-off may be found between the interference and the bandwidth of the rental system (Weiss and Jondral, 2004). In Weiss et al. (2003c), the authors propose the adaptive filtering of the narrowband interferers.

Furthermore, the investment (on the licensed frequencies and technology) protection of the incumbent operators plays an important role concerning the acceptance of opportunistic spectrum access. Weiss and Jondral (2004) proposed a spectrum pooling scenario where secondary users may temporarily rent frequency bands (a pool of bands) owned by licensed users during the idle periods of licensed users. In this way, spectrum pooling can be used to enhance the utilization of spectrum without any change to the licensed systems, which gives a good incentive for the acceptance of the spectrum pooling idea by the incumbent operators. The challenges, the technical requirements and possible solutions for the realization (including frequency-/time-division multiple access, the spectral shape of the transmitted signal, the detection of spectral access, collection and broadcast of spectral measurements, synchronization, etc.) of opportunistic spectrum access are discussed in Weiss and Jondral (2004).

## 3. A performance evaluation framework

Assume that there are $K$ mobile cellular network operators in a certain area. Let $n_k$ be the number of licensed frequency bands of operator $k$, $(k=1,\ldots,K)$, in the area. The number of channels is $\aleph$ in each frequency band. Therefore, the number of channels owned by operator $k$ is $N_k = n_k\aleph$ for $k=1,\ldots,K$. The total number of channels in a specific area is $N=\sum_{k=1}^{K} N_k$.

To construct a mathematically tractable model within the Markovian framework, we follow the classical approach frequently applied in the queueing theory for the performance evaluation of wireless cellular networks (Tzeng and Huang, 2010; Tzeng, 2009;