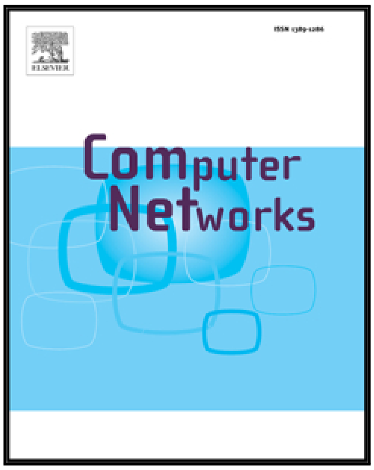

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A Flexible-Bandwidth Model with Channel Reservation and Channel Aggregation for Three-layered Cognitive Radio Networks

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Abstract*— The Fifth Generation (5G) of wireless communication systems is expected to meet a large demand for mobile traffic and provide higher data rates, supporting bandwidth-hungry applications. In this respect, Cognitive Radio and Channel Aggregation (CA) are envisioned as key 5G enablers providing additional spectrum resources through the Dynamic Spectrum Access, and higher data rates through multiple contiguous or non-contiguous spectrum aggregation. Moreover, since 5G networks should comprise heterogeneous applications that may have different Quality of Service (QoS), Quality of Experience (QoE) and security requirements, multiple service class support becomes a must, and thus multiple priorities have been assigned for different flow types in current wireless standards. Previous works have studied Cognitive Radio Networks (CRN) as homogeneous two-priority queueing systems, composed of primary (PUs) and secondary (SUs) users, however, those are usually not capable of analyzing SUs with different QoS requirements. In addition, most authors are concerned about proving the efficiency of QoS provisioning approaches such as channel reservation or channel aggregation, frequently using separate models in unloaded scenarios. This paper proposes and analyzes an M/M/N/N three-layered system in which the unlicensed traffic is detached in two priority classes (i.e., high and low), encompassing all possible bandwidth arrangements, a multi-level reservation feature and multiple aggregation strategies. Previous works on CA have shown that, regardless the network state, this technique should always boost the overall performance, differently from the reservation process that presents high inefficiency in overloaded networks. For this reason, CA was enabled to mitigate the reservation's drawbacks while scaling the benefits of both techniques, in a single model.

***Index Terms*— Cognitive Radio Networks, Dynamic Spectrum Access, Continuous-Time Markov Chains.**

I. Introduction

The mobile traffic has experienced exponential growth due to the bandwidth requirement shift that supports demanding applications such as video streaming and massive machine-to-machine (M2M) communication [1]. The fifth generation (5G) of mobile communications is expected to meet a broader range of applications, which are beyond the capability of previous technologies, requiring spectrum resources to be efficiently managed [2]. Cognitive Radio (CR) has been envisioned as a 5G enabler [3] that helps addressing the strict spectrum requirement, supporting the opportunistic use of the underutilized licensed spectrum through Dynamic Spectrum Access (DSA) and allowing low-cost expansion for wireless systems [4]. Besides, in order to achieve 5G high date rates (10 to 100 times the current 4G speeds), channel aggregation (CA) may scale CR benefits by enabling multiple contiguous or non-contiguous spectrum aggregation that may be of two kinds: macro and micro scale. The first utilizes fixed sized spectrum fragments (e.g., resources blocks - RBs in LTE systems), while the latter uses varying spectrum fragments to be considered in the process [5]. Therefore, higher throughput and flexibility may be achieved through the opportunistic use of underutilized licensed bands (e.g., TV bands) in conjunction to the regular licensed band (e.g., LTE band).

In Cognitive Radio Networks (CRNs), Secondary Users (SUs) opportunistically access the spectrum that is temporarily unused by the licensed users also known as Primary Users (PUs). Since 5G networks should comprise heterogeneous applications (e.g., ultra-high definition video streaming, Web browsing, Marcos Falcao banking, and tactile Internet) that have different Quality of Service (QoS), Quality of Experience (QoE) and security requirements, multiple service class support becomes a must. Current standards such as the IEEE 802.11p for Vehicular Ad Hoc Networks (VANETs) were prepared for the traffic collision possibility, where vital flow types such as those from safety applications may be hindered by the infotainment traffic. So as to protect relevant data, this standard proposes multiple priorities for different flow types and by following this idea, previous authors have built queue-based analytical models to analyze service classes in CRNs, considering either two [6-13] or three priorities [14,15,16,17].

Most authors have proposed inflexible models that are either restricted to cases where the PU bandwidth is larger than the SU´s [11, 14, 15] or the opposite [9, 13, 17]. Hence, scenarios where: (1) a smart grid network (e.g. an advanced metering infrastructure) is employed as a secondary network and ATSC digital TV signals with a bandwidth of 6 MHz characterizes the primary network; and (2) a wireless multimedia streaming network for connected home (e.g. by using 802.11af) [18] is the secondary network and NTSC analog TV signals with 100 kHz bandwidth form the primary system [19] can be rarely represented by a single model. The work developed in [10] is an exception, but is limited for a two-user priority system (homogeneous secondary system). This paper aims to accommodate three user categories in a single CRN (heterogeneous secondary system) with the following access priority order: Primary (PUs), first class SU

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