VoIP over a Cognitive Network with Limited Availability

Yakim Mihov and Boris Tsankov

Abstract—**This paper investigates the call-level performance of a cognitive radio network for dynamic spectrum access providing VoIP service to secondary users. The paper proposes a new cognitive network paradigm, where only a part of the licensed channels are available to the unlicensed users by cognitive functionality. Numerical results are presented and some conclusions are drawn.**

Keywords – C**all blocking probability, call dropping probability, cognitive radio network, limited availability, VoIP.**

I. INTRODUCTION

The term Cognitive radio (CR) was first introduced by J. Mitola [1]. One of the most popular applications of CR is in dynamic spectrum access (DSA) networks, as a means to mitigate the artificially created scarcity of spectrum resources caused by the traditional static approach for spectrum regulation. Hierarchical spectrum overlay is a promising method for DSA. It allows secondary (unlicensed or cognitive) users (SUs) to temporarily utilize spectrum resources assigned to primary (licensed or incumbent) users (PUs) if these resources are not currently being used for PU transmission. SUs have to release the occupied resources as soon as PUs start reusing them, i.e. PUs have preemptive priority over SUs. The cognitive network utilizes opportunistically the available unoccupied spectrum of the primary network on a non-interference basis. Spectrum handover is an essential function of CR since it enables and facilitates the Quality of Service (QoS) provisioning of the SUs.

A popular and often quoted overview of CR is presented in [2]. Due to the great interest in using CR networks for DSA, there are numerous publications in the literature. Spectrum sensing is studied in [3], [4], [5]. Multiuser spectrum selection schemes for spectrum sharing and resolving channel contention are analyzed in [6]. Spectrum handover is investigated in [7], [8], [9]. Various QoS-related issues in CR networks are studied in [10], [11], [12], [13]. The resource allocation problem in a multiuser orthogonal frequency division multiplexing (OFDM) based CR system concerning the QoS provisioning for both real-time and non-real-time applications is investigated in [14]. An overview of the general methodology for cross-layer design and some cross-layer optimization schemes and algorithms are presented in [15]. The voice traffic service is of a particular interest. Some examples are [16], [17], [18], [19], [20], [21], [22].

Arrangement of "cognitive" channels over given spectrum has a certain cost due to realization of functions like spectrum hole detection; detection of PU call arrival over channel occupied by a SU; spectrum handover realization etc. In case the secondary traffic volume does not need all of the licensed channels to be served, it looks rationally the secondary traffic to have access only to some part of the channels of the primary network. Therefore, the "cognitivity" will be arranged to these channels only. As a consequence, operations such as scanning, detection of idle/busy channel conditions, spectrum handover will take place faster as they are performed over a limited number of channels. This paper investigates the voice traffic performance under the circumstances described above.

II. THE TELETRAFFIC SYSTEM

The corresponding teletraffic serving system is shown on Fig. 1. The offered PU traffic is denoted with A_p and the offered SU traffic is denoted with A_s. The PU calls have access to all of the N channels of the primary network. The SU calls have access only to N_c cognitive channels (limited availability). The channels $N_o = N - N_c$ are not subject to cognitive activity, i.e. the secondary CR network is allowed to utilize only the predetermined N_c channels of the primary network. The bandwidth of a SU call is assumed to be equal to the bandwidth of a PU call, i.e. one channel is occupied by one PU or SU call. Perfect spectrum sensing and spectrum handover procedures are assumed. The service of PU calls is independent of the service of SU calls.

A slight system modification is proposed on Fig. 2 where the primary traffic A_p is first directed to the group of N_o channels devoted to PU calls only. Calls rejected from that group of channels represent an overflow traffic directed to the cognitive channels N_c . The cognitive channels form a serving system with PUs and cognitive SUs in accordance with the hierarchical spectrum overlay approach for DSA. PUs have preemptive priority over SUs. If a PU starts transmitting on a

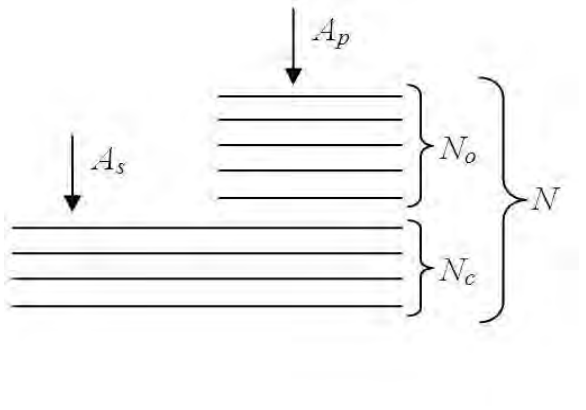

Fig. 1. Illustration of the teletraffic serving system.

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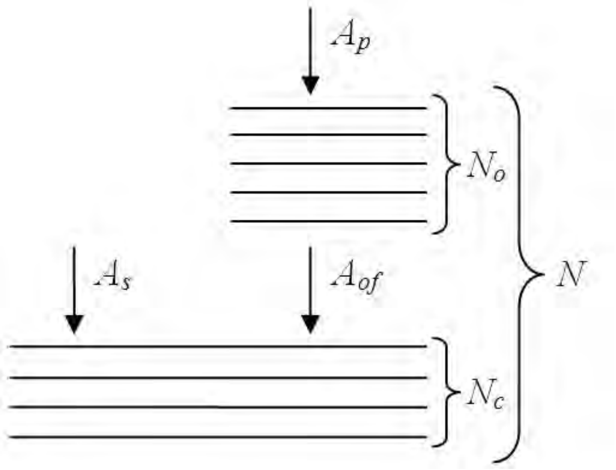

Fig. 2. Illustration of the proposed modified teletraffic serving system.

cognitive channel which is occupied by a SU call, the cognitive channel has to be vacated immediately. In this case, the SU performs spectrum handover to another idle cognitive channel in order to ensure successful call service completion. If there are no idle cognitive channels, the SU call is dropped.

III. PERFORMANCE ANALYSIS

The offered PU and SU traffic is modeled by two Poisson random processes with arrival rates λ_p and λ_s, respectively. The PU and SU call durations follow a negative exponential distribution with mean $1/\mu$. Because of the limited availability of channels to the secondary CR network, it is impossible to apply the traditional method of building a 2-D Markov chain [23] or to find exact and simple closed-form solution of the corresponding steady-state equations and derive important QoS characteristics, such as the SU call blocking probability B_s and the SU call dropping probability B_d.

In the more practical and efficient arrangement proposed on Fig. 2, there is an overflowing traffic A_{of}, which is not a Poisson traffic at all. Because of the preemptive priority of the PU calls over the SU calls, it is impossible to apply the well known *equivalent random theory* [24] used for overflow traffic.

There is not any difficulty to obtain the PU call blocking probability B_p as the service of PU calls is affected neither by the secondary traffic, nor by the cognitive functionality. However, the application of limited availability influences the service of the secondary traffic. This is investigated in the paper by simulations.

IV. SIMULATION RESULTS

In this section, the performance of the secondary CR network with limited channel availability is analyzed by simulation experiments and some insightful conclusions are drawn.

A simulation model has been developed which takes into account all the essential factors necessary for performance evaluation of the described teletraffic system (Figs. 1 and 2), such as the Poisson PU and SU call arrival flows, the random service time of a PU or SU call with negative exponential distribution, the preemptive priority of PU calls over SU calls, and the application of limited channel availability for the CR network. Moreover, the proposed system modification (see Fig. 2) has also been implemented as an option in the simulation model.

We first analyze the effect of the number of available channels to the secondary CR network (i.e. the number of cognitive channels) N_c on the cognitive traffic capacity when some predefined level of SU QoS provisioning (in terms of SU call blocking probability B_s and SU call dropping probability B_d) has to be guaranteed. As N_c decreases, the traffic capacity of the CR network decreases as well (see Fig. 3). Therefore, the limitation of the availability of the PU channels for DSA comes at the price of reduced cognitive traffic capacity, which is undesirable if the offered SU traffic that has to be served by the CR network is relatively large. However, when the offered SU traffic is relatively small, a reasonable decrease in the capacity of the CR network due to limited channel availability would not degrade the service of SU calls. The limitation of the cognitive channels, i.e. the use of a predefined subset of PU channels for DSA, may be desirable since the procedures and operations for supporting the “cognitivity” of the secondary network do not have to be performed on all of the channels of the primary network, i.e. the cognitive processing load (including procedures such as spectrum sensing, spectrum analysis, spectrum handover, etc.) can be reduced significantly, which is especially favorable in a resource-constrained cognitive environment.

Next, we analyze the effect of the offered PU traffic A_p on the traffic capacity of the secondary CR network when given

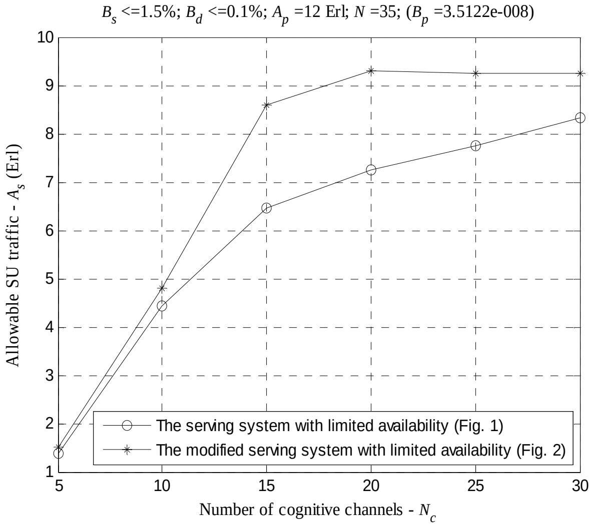

Fig. 3. Cognitive traffic capacity versus the number of channels available to the secondary CR network.

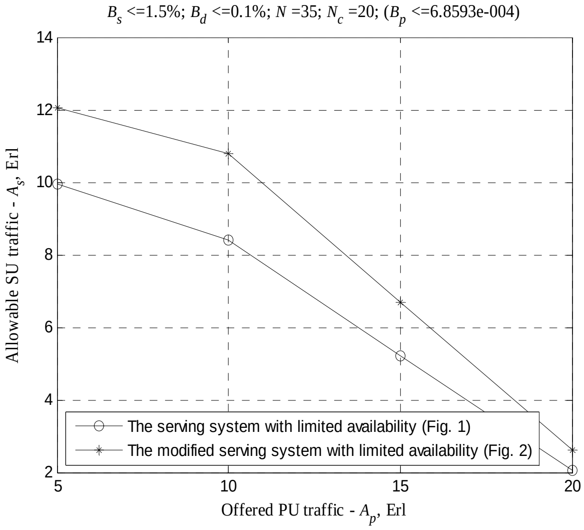

Fig. 4. Cognitive traffic capacity versus the offered PU traffic.

SU call blocking probability B_s and SU call dropping probability B_d have to be maintained. As A_p increases, the maximum allowable offered SU traffic A_s decreases (see Fig. 4). Consequently, the traffic capacity of the CR network depends on the PU traffic load and the use of CR for DSA is rational in primary networks with sufficiently underutilized transmission resources.

Finally, we analyze the effect of applying the proposed modification of the serving system (see Fig. 2) on the performance of the secondary CR network. Figs. 3 and 4 show that the modified serving system provides greater cognitive traffic capacity. Because of the suggested modification of the serving system, the channels $N_o = N - N_c$ (that are not used for DSA) are more likely to be occupied by PU calls than the N_c cognitive channels, which leads to a reduction in the SU call dropping probability B_d. Similarly, the probability for spectrum handover of ongoing SU calls decreases as well, which facilitates the QoS provisioning in the CR network, since under certain circumstances spectrum handover could cause intolerable transmission delay. Therefore, the application of the proposed slight modification to the serving system considered herein improves considerably the performance of the secondary CR network.

V. CONCLUSION AND FUTURE WORK

In this paper, the call-level performance of a VoIP secondary CR network operating over a VoIP primary network in accordance with the hierarchical spectrum overlay approach for DSA is investigated in the specific case when DSA is performed only on a predefined subset of primary channels. The simulation results presented in this paper prove the feasibility of the proposed new paradigm for DSA with limited availability. The main advantage of DSA with limited availability is that the cognitive processing load can be significantly reduced. Moreover, the risk of causing intolerable interference to the primary network due to spectrum sensing errors is considerably reduced, since some channels of the primary network are never occupied by SU calls.

The suggested modification of the investigated serving system with limited availability leads to considerable performance enhancement of the secondary CR network in terms of increased cognitive traffic capacity and reduced probability for spectrum handover of ongoing SU calls.

For future research work, the authors plan to develop algorithms for determining the optimal number of primary channels available for DSA based on different design criteria.

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