A New Cognitive Network Paradigm with Licensed Channels

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ABSTRACT: *To ensure better access to the VoIP service to all end-users, we need a better performance of cognitive radio networks for dynamic spectrum. In this paper, we presented a new cognitive network paradigm, where some licensed channels are available to unlicensed users by cognitive functionality. We have presented the extensive results and further highlighted the meaningful inferences.*

Keywords: Call Blocking Probability, Call Dropping Probability, Cognitive Radio Network, Limited Availability, VOIP

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1. 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 noninterference 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.

2. The Teletraffic System

The corresponding teletraffic serving system is shown on Figure 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 Figure 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 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.

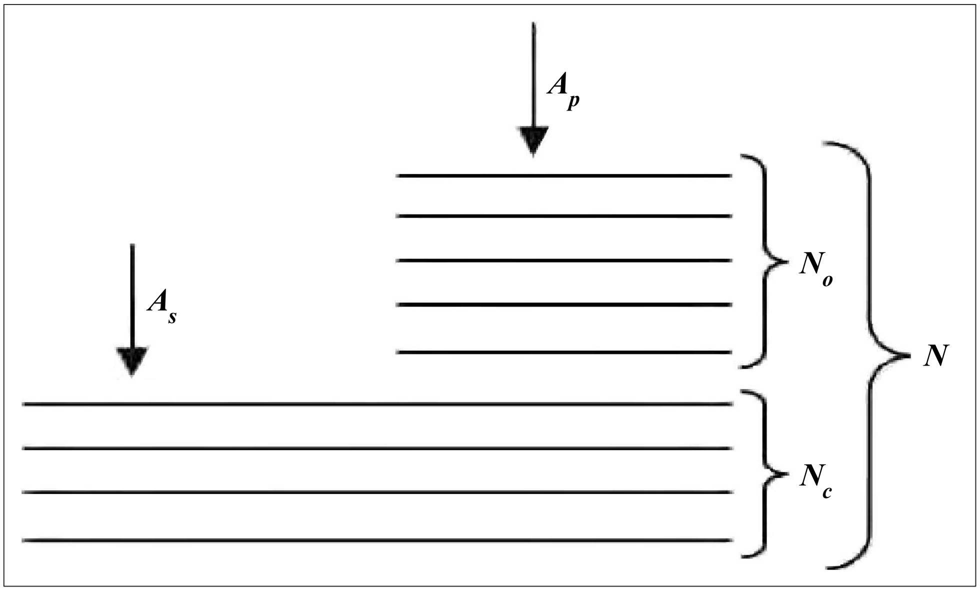

Figure 1. Illustration of the teletraffic serving system

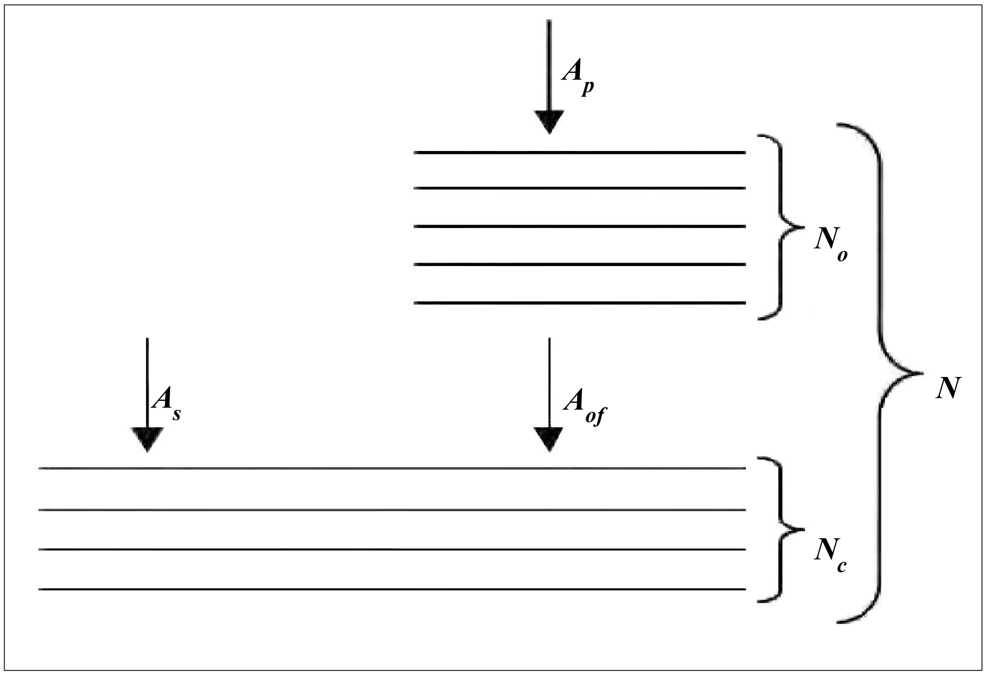

Figure 2. Illustration of the proposed modified teletraffic serving system

3. 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 an $1/\mu$. 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 Figure 2, there is an overflowing traffic $\acute{A}_{of}$, 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.

4. 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 (Figures. 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 Figure 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 Figure 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.

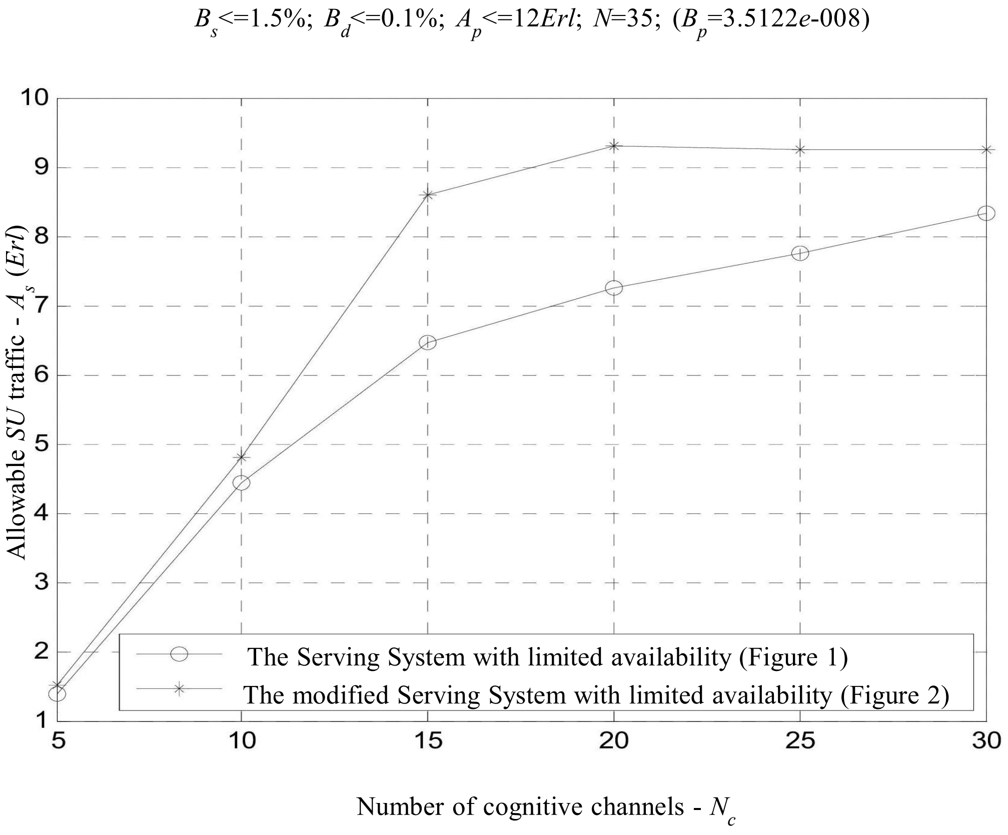

Figure 3. Cognitive traffic capacity versus the number of channels available to the secondary CR network

Next, we analyze the effect of the offered PU traffic A_p on the traffic capacity of the secondary *CR* network when given *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 Figure 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 Figure 2) on the performance of the secondary *CR* network. Figures 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.

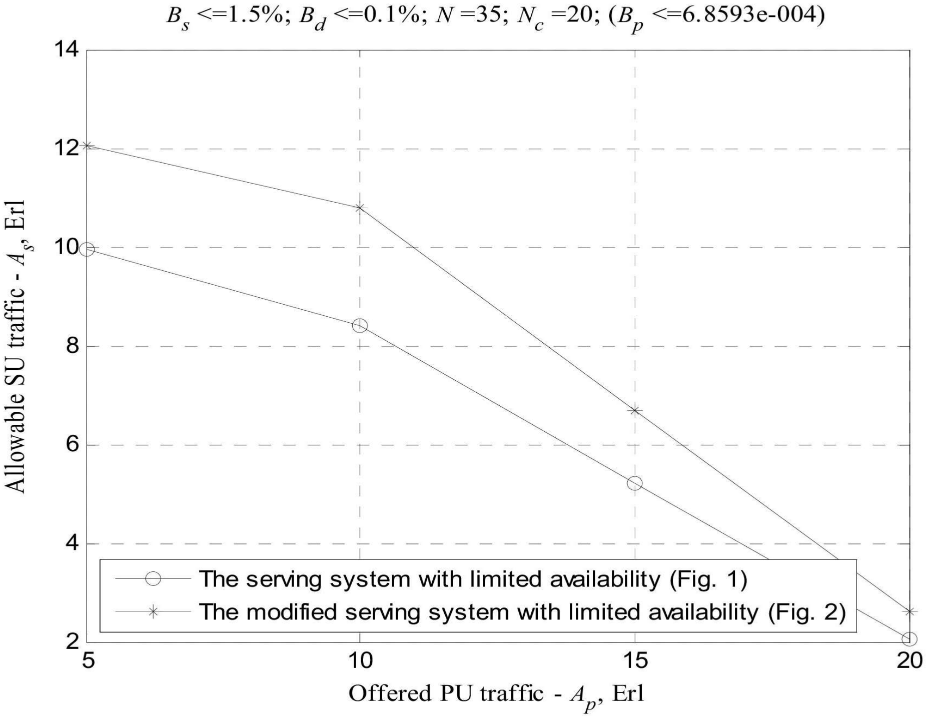

Figure 4. Cognitive traffic capacity versus the offered PU traffic

5. 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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