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Optimal channel switching in multiuser systems under average capacity constraints ☆

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ABSTRACT

In this paper, the optimal channel switching problem is studied for average capacity maximization in the presence of multiple receivers in the communication system. First, the optimal channel switching problem is proposed for average capacity maximization of the communication between the transmitter and the secondary receiver while fulfilling the minimum average capacity requirement of the primary receiver and considering the average and peak power constraints. Then, an alternative equivalent optimization problem is provided and it is shown that the solution of this optimization problem satisfies the constraints with equality. Based on the alternative optimization problem, it is obtained that the optimal channel switching strategy employs at most three communication links in the presence of multiple available channels in the system. In addition, the optimal strategies are specified in terms of the number of channels employed by the transmitter to communicate with the primary and secondary receivers. Finally, numerical examples are provided in order to verify the theoretical investigations.

1. Introduction

Optimal power allocation has critical importance for enhancing performance of communication systems. For example, in fading environments, performance of communication between two users can be improved by employing an efficient power allocation strategy (e.g., water-filling algorithm [1]) compared to the conventional uniform power allocation approach. In the literature, the studies related to power allocation have mostly focused on the performance metrics such as channel capacity (e.g., [1–3]), bit error rate (BER) (e.g., [4–8]), and outage probability (e.g., [9–11]) in general. In [1], the optimal power allocation strategy is derived for capacity maximization over a fading additive white Gaussian noise (AWGN) channel in the presence of perfect channel state information (CSI) at both the transmitter and the receiver. It is obtained that the optimal strategy that maximizes the channel capacity is the water-filling solution in which more power is allocated to better channel states if the signal-to-noise ratio (SNR) is above a certain threshold and no power is transmitted otherwise. Via optimal power allocation, the ergodic capacity and the outage capacity is maximized in [2] for secondary users in a cognitive radio network. In a similar context, the optimal power allocation schemes are considered in [4] for cognitive radio networks in order to minimize the average BER of secondary users. In [9], the optimal power allocation is studied in order to reduce the outage probability in fading channels.

In addition to the power allocation approach, time sharing (i.e., randomization) is another method for improving performance of communication systems. The mechanism behind the benefits of the time sharing (randomization) method is related to a phenomenon called stochastic resonance (SR). The counterintuitive effects of SR provides performance benefits in the context of statistical average for a system in which nonlinearities and suboptimal parameters are observed [12,13]. In the literature, the time sharing approach has been studied in the context of noise enhanced detection and estimation (e.g., [14–18]), error performance improvement (e.g., [16,19–24]), and jamming performance enhancement (e.g., [25–27]). Although an increase in the noise degrades the system performance in general, addition of noise to a system in conjunction with time sharing among a certain number of signal levels can provide performance benefits [14–18]. In a similar context, stochastic signaling, i.e., time sharing among multiple signal values for each information symbol, is performed for average power constrained non-Gaussian channels to improve the error performance of the system [19,20]. In [19], it is presented that randomization

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(time sharing) is required among no more than three different signal values in order to achieve the optimal error performance in the presence of second and fourth moment constraints. Also, time sharing among multiple detectors (i.e., detector randomization) is employed over additive time-invariant noise channels [16,21]. In [16], it is obtained that time sharing between two antipodal signal pairs and the corresponding maximum a-posteriori probability (MAP) detectors can significantly enhance the system performance in the presence of symmetric Gaussian mixture noise. In a similar manner, the study in [21] investigates both detector randomization and stochastic signaling approaches for an M-ary communication system in which an additive noise channel is considered with a known distribution. In the context of jamming performance enhancement, a jammer can employ time sharing among multiple power levels in order to reduce the detection performance of a receiver or to degrade the error performance of a communication system [25–27].

In the presence of multiple channels in a communication system, time sharing (i.e., channel switching) can be employed to enhance certain performance metrics such as average probability of error, average number of correctly received symbols, and channel capacity [28–31]. The channel switching problem is studied in [28] for M-ary communication systems in which a transmitter communicates with a receiver by employing a stochastic signaling approach in order to minimize the average probability of error under an average power constraint. It is shown that the optimal strategy corresponds to either one of the following strategies: deterministic signaling over a single channel, time sharing between two different signal constellations over a single channel, or time sharing between two channels with deterministic signaling over each channel. The channel switching problem is also studied in [29] for maximizing the average number of correctly received symbols between a transmitter and a receiver in the presence of average power and cost constraints. It is proved that the optimal strategy corresponds to channel switching either among at most three different channels with full channel utilization (i.e., no idle periods), or between at most two different channels with partial channel utilization. Unlike the studies in [28] and [29], the channel switching strategy is employed together with power allocation in order to enhance the *capacity* of a communication system in [30,31]. In [30], the optimal channel switching strategies are investigated for a communication system in which a single transmitter communicates with a single receiver in the presence of the average and peak power constraints. It is obtained that the optimal channel switching strategy corresponds to the exclusive use of a single channel or to channel switching between two channels. In [31], the study in [30] is extended for a communication system where the channel switching delays (costs) are considered due to hardware limitations. It is shown that any channel switching strategy consisting of more than two different channels cannot be optimal.

Although the channel switching problem has been studied for communication between a single transmitter and a single receiver in the presence of average and peak power constraints and in the consideration of channel switching delays, no studies in the literature have considered the channel switching problem in the presence of multiple receivers in the communication system. In this study, a transmitter communicates with two receivers (classified as primary and secondary) by employing a channel switching strategy among available multiple channels in the system. The aim of the transmitter is to enhance the average capacity of the secondary receiver while satisfying the minimum average capacity requirement for the primary receiver in the presence of average and peak power constraints.[1] Also, due to hardware limitations, the transmitter can establish only one communication link with one of the receivers at a given time by employing one of the communication channels available in the system. It is obtained that if more than one channel is available, then the optimal channel switching strategy which maximizes the average capacity of the secondary receiver consists of no more than 3 communication links. (It is important to note that each channel in the system constitutes two communication links; that is, one for the communication between the transmitter and the primary receiver and one for the communication between the transmitter and the secondary receiver.) In addition, with regard to the number of channels employed in the optimal channel switching strategy, it is concluded that the transmitter either communicates with the primary receiver over at most two channels and employs a single channel for the secondary receiver, or communicates with the primary receiver over a single channel and employs at most two channels for the secondary receiver. In addition to the communication system with a single primary receiver, the channel switching problem in this study is also extended for communication systems in which there exist multiple primary receivers, each having a separate minimum average capacity requirement for the communication with the transmitter. Lastly, numerical examples are provided to exemplify the theoretical results.

Compared to this manuscript, the studies in [30] and [31] do not consider the multi-user scenario and consequently the optimal channel strategies obtained in those studies are not applicable for a communication system in which multiple users communicate with each other. Even though the studies in [30] and [31] do not provide any approaches for multi-user communication systems, they constitute a fundamental aspect for the optimal channel switching strategies obtained in this manuscript. Therefore, the methods and approaches employed in this study bear a certain level of resemblance to those in [30] and [31]. On the other hand, it is important to note that the contributions of this study to the literature are significantly different from the ones in [30] and [31]. More precisely, the constraint related to the minimum average capacity requirement of the primary receiver in the communication system modeled in this study alters the analysis of the optimal channel switching strategy and requires new proof approaches that are mostly different from the ones employed in [30] and [31].

The main contributions of this paper can be summarized as follows:

- For the first time in the literature, the channel switching problem is studied for average capacity maximization in the presence of multiple receivers in a communication system where the transmitter communicates with the primary and secondary receivers in order to improve the average capacity of the secondary receiver under the average and peak power constraints and the minimum average capacity requirement for the primary receiver.
- It is obtained that the optimal channel switching strategy includes no more than 3 communication links in the presence of multiple available communication channels in the system.
- It is shown that the optimal channel switching strategy corresponds to one of the following strategies:
  - The transmitter performs communication with the primary receiver over at most two channels and employs a single channel for the secondary receiver.

[1] In this study, the channel switching delays are omitted in order to simplify the system model. However, the main contributions of the manuscript are valid in the presence of switching delays, as well.