STATISTICAL RESOURCE ALLOTMENT FOR MULTI-BAND COGNITIVE RADIO SYSTEMS: AN OVERVIEW OF PORTFOLIO OPTIMIZATION METHOD

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Abstract

A recent development in wireless communications is Cognitive Radio (CR) technology, an innovative design approach which allows the realization of optimal allocation of the scarce radio resources such as the spectrum. Successful resource allocation in CR systems has to overcome the uncertainty of spectrum bands availability as well as the chaotic wireless propagation environment. Previously, most research in resource allocation in CRs has mainly concentrated on the spectrum opportunity discovery aspect while the robust QoS performance problem has remained largely unexplored. In this paper, we discussed about, jointly consider the power control and spectrum band discovery problems under uncertain CR operative environments. This problem setting is a direct analogy of the portfolio optimization (PO) concept. In PO, once the variance of return is known, then an investor can use the information to find a wealth allocation strategy so as to minimize the investment risk. Similarly, in uncertain CR scenarios, once the variance of a QoS parameter (e.g., throughput) is known, then a power allocation strategy can be obtained leading to re-liable communication. The resulting power strategy also marks out the subbands to be used essentially achieving soft spectrum sensing. In this work, we give the overview of portfolio optimization to jointly achieve power control and subband allocation over uncertain CR environments. The limitations of the approaches are investigated through the sensitivity analysis of the solutions obtained. A raw data processing approach will also be given leading to an alternative algorithm for stable data processing.

Introduction

Future wireless communication systems are expected to have the intelligence to perform trade-offs between user quality of service (QoS) requirements and scarce radio resources constraints. This intelligence will be based on the innovative cognitive radio (CR) design philosophy which allows for devices to make clever decisions on spectrum usage, power allocation, type of network service to access/subscribe, collaboration with other devices etc., while meeting QoS requirements [5, 7]. Recently, environment sensing, specifically spectrum sensing, which is the first stage of the cognition process, has attracted a lot of research interest. However, work on the exploitation of the information obtained to achieve the intelligent and ubiquitous communication goal is still at its infancy.

Multi-carrier transmission, specifically OFDM (Orthogonal Frequency Division Multiplexing) has been taped for the high bit rates demanded by current and emerging applications [6, 4]. These includes IEEE802.11 (WiFi- Wire-less Fidelity) [1], digital audio broadcasting (DAB) [3], digital video broadcasting (DVB) [?] and IEEE802.16 (WiMAX - Worldwide Interoperability for Microwave Access) [2]. The modularity of OFDM and the fact that it is adopted in many current and future systems makes it favorable for the transceiver design of CR wireless systems.

More importantly, the use of orthogonal signaling and the inherent frequency diversity in a well-designed OFDM system are especially useful in attempting to dynamically satisfy the system’s QoS requirements (such as throughput or delay constraints) while tracking changes in the availability of resources. This is because the availability of resources, such as spectrum, might not be contiguous due to their use by higher priority users (licence holders, or primary users) or radio channel degradation.

The multi-carrier system which dynamically operates in non-contiguous frequency bands and enabled by cognition technology is referred to as non-contiguous OFDM (NC-OFDM) [10, 8]. The flexibility offered by cognitive radio transceivers and NC-OFDM can be employed to design an efficient resource allocation mechanism through power control, sub-band or sub-carrier selection, bit loading and other innovative parameter abstractions for flexible transceiver adaptation. Achieving these gains, however, depends on devising practical resource allocation strategies which jointly considers the uncertainties of the resource availability and user QoS requirements. Previous work on conventional OFDM systems is based on an implicit assumption that the allocated transmission spectrum is fixed and always available along with an explicit assumption that the channel variations are quasistatic. In such scenario, QoS
satisfaction is achieved by exploiting the time varying nature of the fading gains across the subcarriers through adaptive modulation and power loading schemes [4]. However, this approach might not be directly applicable to the NC-OFDM CR systems.

In CR networks, the spectrum is co-shared and the operating bandwidth is not continuously available in the time, frequency and geographical domains. In situations where the channel is changing too quickly to be tracked, reliable feedback of the channel state information (CSI) to the transmitter is also compromised. In such cases, it is difficult to model a mere rate maximization or power minimization problem while considering the changes in the transmission channel and bandwidth. Fig. 1 gives an illustration of such situation where the CR is operating as a secondary spectrum user under a dynamic spectrum usage scenario and hence subject to interference and usage patterns of the primary users or licence holders. In this particular case where the available bandwidth is changing and there is imperfect CSI at the transmitter (CSIT), trying to ensure QoS under power constraints is a daunting task. In this paper, we the analysis of statistical approach and consider an imperfect CSI at the transmitter (CSIT), trying to ensure QoS under power constraints is a daunting task. In this paper, we the analysis of statistical approach and consider an NC-OFDM CR communication link under varying available bandwidth and imperfect CSIT.

The organization of this paper is as follows. In Section 2, we describe where the spectrum sharing scenario is given and the NC-OFDM based data transmission system is introduced. An overview of the portfolio optimization theory is given in Section 3.

Figure 1: Bandwidth activation in an NC-OFDM CR operative environment. The CR dynamically deactivates or activates frequency bands depending on whether the primary user is present or not.

System framework

Spectrum sharing scenario
We assume an interference controlled spectrum sharing scenario. In this general case, primary users or licence holders allow secondary spectrum usage, whereas a secondary spectrum user is under certain interference limitations imposed by the licence holder as well as primary user traffic patterns. We assume that a secondary spectrum user operates in a limited bandwidth (which could span different licence holders) divided into N subchannels, which make a set N of usable subchannels. At any communication session, there is a variable NON ∈ N amount of subchannels available for data transmission. This scenario has three implications with respect to conventional assumptions:

1. Operational bandwidth is flexible and not fixed: Notice that in conventional OFDM systems, it is explicitly assumed that a fixed bandwidth is available. This simplifies the rate or power optimization problems. However, in our case the amount of bandwidth or number of subchannels available is a variable.

2. Unpredictable channel variations: In the conventional case, channel changes are typically assumed to be quasi-static. However, in a spectrum sharing scenario, it might not be the case. In fact, the characterization of CR based channels is still an open problem.

3. Learning modeling: Since CRs are expected to have a human knowledge ability to learn their environment and make decisions accordingly, it is obvious that conventional approaches provides no room for developing such functionality.

In this uncertain setting, the task of ensuring QoS performance will require a robust framework. But is to use past subchannel’s CSI and through an appropriate power allocation, our aim is to minimize the variance of a transmission rate benchmark rdes. That is, we determine which are the subchannels to make up the NON , and how much power should be allocated in each to maintain rdes under limited power constraints.

Data transmission
Consider an NC-OFDM transceiver as shown in Fig. 2. At the transmitter, Fig. 2(a), a high speed input data stream x(n) with r bits per transmission epoch is split into lower rate substreams. In this case,

\[ r = 1^T \]  

(1)

where \( i \in [1, \ldots, N \text{ or } T] \) and \( r = [r_1, \ldots, r_N \text{ or } T] \). The value \( r_i \), bits per transmission epoch for subcarrier \( i \), is assigned by a loading algorithm which maps the subcarrier’s signal-to-noise ratio (SNR) values (denoted as \( i \)) to the corresponding constellation and coding mode that satisfies a target bit error rate (BER) [19,20]. That is,

\[ r_i = f(y_i, \text{BER}) \]  

(2)
where the function $f(.)$ is upper bounded by the Shannon capacity formula. Given the BER value, the $f(.)$ function adopted to express the achievable data rate at the $i$th subchannel is

$$f(y_i, \text{BER}) = \log_2(1 + \beta y_i)$$

where $\beta = -1.5/\ln(5\text{BER})$ is called the SNR gap, which indicates the gap of SNR needed to reach a certain capacity between practical implementations and information theoretical results over fading channels [21, 22].

The modulator translates the bit-stream by using M-ary phase shift keying (MPSK) or M-ary quadratic amplitude modulation (MQAM) into symbol $X_i$, chosen from one of the $M$ appropriate constellation where $M_i$ consists of $2ri$ points. In the NC-OFDM CR system considered here, the channel sounding and spectrum analysis module jointly process the information about the spectral availability and channel statistics across the transmission bandwidth which will be used for the QoS maintenance process through minimizing the variance by allocating power so as to satisfy the expected $i$ per subcarrier. The detection of the transmitted NC-OFDM signal is performed in a reverse order as illustrated in Fig. 2(b). The $i$th subchannel signal-to-noise ratio is given by

$$y_i = \frac{P_i |H_i|^2}{2\sigma_i}$$

Figure 2: Non-contiguous OFDM transceiver

where $P_i$ is the power allocated, $|H_i|^2$ is the channel gain and $\sigma_i$ is the noise power on sub channel $i$. We define the CSI as

$$G_i = \frac{|H_i|^2}{\sigma_i}$$

$$y_i = P_i G_i$$

Portfolio optimization overview

Portfolio optimization is a powerful analogy for studying intelligent resource allocation in autonomous CR devices. For the sake of completion, we give a brief overview of the portfolio theory which was introduced by Markowitz. A comprehensive presentation of the subject matter can be found in [9] and other related literature.

The main goal of an investor is to achieve optimal allocation of funds among his/her various financial assets. Searching for the optimal stock portfolio, characterized by random future returns, is a challenging task and is usually formalized as a risk-minimization problem under a constraint of expected portfolio return. Portfolio risk is often measured in terms of the variance of the returns, but many other risk criteria have been proposed in the financial theory. In our adoption of the theory for resource allocation in CR systems, we shall restrict our consideration to the variance of return formalization.

Consider a financial market in which X risky assets (subcarriers) are traded. Let $y = y_1, y_2, ..., y_X$ be the random vector of their returns (CSI). We denote $y = E(y)$ to be the vector of expected returns and $\varphi$ the corresponding covariance matrix with is assumed to be positive definite. A portfolio is a vector $w \in RX$ verifying $wT e$ where $e$ is a $X$-component vector of ones. Hence, $w e$ is the proportion of wealth (power, SNR) invested in the $X$-th asset. Denote $W$ as the set of all portfolios $T$. For each $w \in W$, we define $y w = wT y$ as the portfolio return and then $w \ y = Ey w$ is the portfolio of expected return (expected SNR at the receiver).

For a fixed level $y b$ of expected return, $W y_b = w \in W : wT y = yb$ optimization problem is then to find $w$ such that

$$\text{Risk}(\bar{w}) = \min \text{Risk}(w) : w \in W y_b$$

Conclusion

Cognitive radios operating in dynamic spectrum sharing environments are faced with uncertainty regarding the availability of communication resources such as the spectrum. In this paper, we have taken preliminary steps in pragmatic formulation of a power control and subband (subchannel) allocation in uncertain CR operative environments based on the portfolio optimization theory. The problem has been cast into a CSI variance minimization problem where power is allocated under BER and power limit constraints to maintain the desired QoS level. With some simplification, two possible user approaches have been considered namely variance minimization and mean-variance maximization.

References


