Abstract:

In this paper proposed water filling algorithm is discussed which has been used for allocating the power to the MIMO channels in cognitive radio network so as to enhance the capacity of the network. Here we present a theoretical framework for allocating the power considering a 4x4 MIMO system and the system is assumed to be MIMO-OFDM based cognitive network and the channel to be flat as under this the convolution integral becomes a simple multiplication operator. In this paper we study the comparison of various systems with and without the proposed water filling algorithm for the available power budget. It can be observed from the graphs that the efficiency of the system is enhanced with the proposed water filling algorithm and also it is observed that the outage probability shows constant value as compared to the outage observed in the systems without the water filling algorithm. It is further seen that there is enhancement in the capacity of a MIMO system.

Keywords: Cognitive Radio, MIMO-OFDM, Water Filling, outage probability, system capacity

1. Introduction

The MIMO system has multiple transmit and receive antennas and Orthogonal Frequency-Division Multiplexing (OFDM) is used as it is sought as one of the solution for increasing the capacity and data rate of a system in an environment where the communication take place in a frequency-selective fading environments and there can be probably more chances for data corruption. It has been found that Multiple-Input and Multiple-Output (MIMO) can be effectively used to increase the capacity of the system by a factor of the minimum number of transmitter and receiver antennas attached in the MIMO system as compared to a Single-Input Single-Output (SISO) system that has flat fading or frequency selective fading environment or narrowband channels, OFDM can also increase diversity gain and minimize the inter-symbol interference on a time-varying multi-path fading channel. When we know the parameters of the channel both at the transmitter end and at the receiver end, we can further increase the capacity of MIMO OFDM systems by assigning power at the transmitter according to the water filling algorithm to the channels.

A cognitive radio is a transceiver which automatically detects available channels in wireless spectrum and accordingly changes its transmission or reception parameters so more wireless communications may run concurrently in a given spectrum band at a place. Therefore, regulatory bodies in the world have been considering to allow unlicensed users in licensed bands if they would not cause any interference in licensed users. Cellular networks bands are overloaded in most parts of the world, but other frequency bands are insufficiently utilized. Therefore, regulatory bodies in the world have been considering to allow unlicensed users in licensed bands if they would not cause any interference to licensed users. These initiatives have focused cognitive-radio research on dynamic spectrum access.
2. Related work

A lot of work has been already done on the resources allocation in non-cognitive and cognitive relay systems. In [5], the authors proposed an algorithm to select the best transmit way between the network nodes. The algorithm can select direct, dual or diversity transmission based on the available spectrum as well as the maximum allowable transmission powers. In [4] the authors studied a proposed algorithm which has a much lower computational complexity and the performance is close to optimal scheme but outage probability has no change. In [6] optimal resource allocation is done in cognitive networks with interference constraints with the available power budgets. In [19] it is seen that the proposed algorithm has a much lower computational complexity and the performance is close to optimal scheme but no information of outage probability.

To the best of our knowledge, no one has analysed the capacity and outage probability of cognitive radio networks together except the resources allocation. The main contributions of the paper are the capacity and outage probability analysis of the secondary users with the help of water filling algorithm by using some mixed integer programming problem taking into account that the different relays are applying DF-protocol.

3. System Model

A one-cell wireless system, in which the PU and SU transceivers coexist in the same geographical location is considered. The scenario is investigated for downlink path and for a CR user. PUs’ base station transmits signals to N PUs, each of which occupies a determined frequency band in the available spectrum. Suppose that the CR base station and the CR user have NT and NR antennas, respectively. The SU MIMO channel for ith sub-carrier is denoted by an N × M matrix Hi where its element hi, n, m denotes the channel gain for the channel between the mth transmit and the nth receive antenna. The channel gain between the SU transmitter and the lth PU receiver for the ith sub-carrier is denoted by a 1 × M matrix, where gi, l, m denote the channel gain for the channel between the SU’s mth transmit antenna and the lth PU receiver antenna.

Since we assumed that the transmitter has the perfect CSI, each sub-carrier channel can be decomposed into parallel independent sub-channels by singular value decomposition (SVD).

\[ H_i = U_i A_i V_i^* \]  \hspace{1cm} (1)

Where \( U_i \in C^{NR \times NR} \) and \( V_i \in C^{NR \times NT} \) are unitary matrices and \( A_i \in C^{NR \times NT} \) is a rectangular matrix whose diagonal elements are non-negative real numbers. The diagonal elements \( \lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_{n_{\min}} \) are the ordered singular values of the matrix Hi, where \( n_{\min} = \min(N_R, N_T) \).

4. Proposed Water Filling algorithm

Water filling is a metaphor for the solution of several optimization problems related to channel capacity. Water filling refers to a technique whereby the power for the spatial channels are adjusted based on the channels gain. The channel with high gain and signal to noise ratio is given more power. More power maximizes the sum of data rates in all sub channels. The data rate in each sub channel is related to the power allocation by Shannon’s Gaussian capacity formula \( C = B \log_b (1 + SNR) \). However, because of the capacity is a logarithmic function of power, the data rate is usually insensitive to the exact power allocation. This motivates the search for simpler power allocation schemes that can perform close to the optimal. The total amount of water filled (power allocated) is proportional to the Signal to noise ratio of the channel.

The Capacity of a MIMO system is algebraic sum of the capacities of all channels and is given by the formula below.

\[ \text{Capacity} = \sum_{m=1}^{B} \log_2 (1 + \text{Power:Allocated} \times H) \]  \hspace{1cm} (2)

we have to maximize the total number of bits to be transported.
Algorithm steps:
1. Take the inverse of the channel gains. Water filling has non-uniform step structure due to the inverse of the channel gain.
2. Initially take the sum of the total power Pt and the inverse of the channel gain. It gives the complete area in the water filling and inverse power gain.
3. Decide the initial water level by the formula given below by taking the average power allocated.
4. The power values of each sub-channel are calculated by subtracting the inverse channel gain of each channel. In case the power allocated value become negative stop iteration.

\[
P_t + \sum_{i=1}^{n} \frac{1}{H_i} - \sum \text{channels} - \frac{1}{H_i}
\]  

(3)

Where P_t is the power budget of the MIMO system which is allocated among the different channels and H is the channel matrix of the systems.

5. **MIMO-OFDM Capacity And Outage Probability**

Consider a MIMO OFDM system with \(N_r\) receivers and \(N_t\) transmit antennas. The system is represented as

\[
Y = hx + n
\]  

(4)

Where ‘x’ is the \((N_t \times 1)\) transmit vector, ‘y’ is the \((N_r \times 1)\) receive vector, ‘h’ is the \((N_t \times N_r)\) channel matrix and ‘n’ is the \((N_r \times 1)\) additive white Gaussian noise (AWGN) vector at a given instant in time. Generally the channel matrix is denoted by \(\{h_{ji}\}\) and this represents the complex gain of the channel between the \(j^{th}\) transmitter and the \(i^{th}\) receiver.

The channel capacity is associated to an outage probability. Capacity treated as random variable depends on the channel instantaneous reasons and remains constants. If the channel capacity falls below the outage capacity there is no possibility that the transmitted block of information can be decoded with no errors, in which error coding scheme employed. The outage probability is

\[
P_{out} = P_T \left[ \log \det \left( I_{N_r} + h Q h^+ \right) < R \right]
\]  

(5)

Where \(Q = E[HH^+]\) is covariance, R is information rate to be transmitted. It is conjectured that \(P_{out}\) is minimized by using a uniform power allocation over a subset of the transmit antennas.

6. **Simulation Results**

The channel mean capacity vs SNR curve of different systems is shown in figure 2. It is shown that the mean capacity of the MIMO system with proposed water filling has higher capacity than those without water filling algorithm at the available power budget. And also when a graph is plotted with outage probability Vs SNR it is observed that the MIMO system with proposed algorithm has constant outage probability than other systems.

![Figure 2: Plot of Mean Capacity Vs SNR in dB](image)

![Figure 3: Plot of outage probability Vs SNR in dB](image)

7. **Conclusion**

In this paper, we investigated the power allocation scheme for CR networks, employing the MIMO–OFDM structure. It has been shown analytically that the conventional power loading algorithm cannot be
used in CR networks. Then, we proposed a new algorithm that maximise the transmission capacity of CR users; meanwhile the interference introduced to the PUs remained below the specific threshold. Furthermore, it described the Mean capacity allocation in a wireless cellular network based on the water filling power allocation in order to enhance the capacity of a MIMO systems with different channel assumptions. Here each transmitter decide the distribution of power to the several independent fading channels. Results indicates that the water-filling scheme has better capacity than without water filling with the available power budgets. The variation in outage probability is also discussed. In future we can try to to increase the sensing of spectrum in CR network and make avail more CR application with less expenditure systems.

References


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