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HYBRID SHARING AND POWER ALLOCATION USING WATERFILLING ALGORITHM FOR MIMO-OFDM BASED COGNITIVE RADIO NETWORK

Sandeep Kumar Jain[1] and Baljeet Kaur[2]

[1]*Department of Electronics and Communication Engineering, I.K. Gujral Punjab Technical University, India*

[2]*Department of Electronics and Communication Engineering, Guru Nanak Dev Engineering College, India*

Abstract

In order to optimize power allocation, Orthogonal frequency division multiplexing (OFDM) based cognitive radio (CR) network allows flexible spectrum and adaptive capability. Decreased capacity due to subcarrier cancelation and out of band reduction can be compensated while employing multiple inputs and multiple outputs (MIMO) along with OFDM based CR. MIMO allows better beam forming and directivity due to multiple transmit and receive antenna. Here we have implemented water filling mechanism with channel state information (CSI) for optimal power allocation under hybrid spectrum sharing scenario such as overlay, underlay and interweave. Main objective is to maximize overall capacity of cognitive radio network in downlink while considering interference constraint imposed by primary user and maximum transmit power constraint at secondary user. Simulation results demonstrate waterfilling approach for hybrid scenario in MIMO-OFDM based CRN.

Keywords:

Cognitive Radio, MIMO, OFDM, Waterfilling

1. INTRODUCTION

Demand of available spectrum band for high data rate, better throughput and superior quality in services escalating rapidly that brings in spectrum scarcity problem. On the other hand, it has been observed that most of the licensed allocated bands are under-utilized [1]. In order to resolve both spectrum scarcity and spectrum under-utilization issues, FCC commence an intelligent radio system known as cognitive radio system [2], [3], that may be used to realize dynamic spectrum allocation (DSA) [4] and opportunistic spectrum sharing. CR is capable to be aware of outer world in which it is operating and can fiddle with its transmitting parameters accordingly. In order to do so, foremost essential but rendered complicated task of CR is to sense and trustworthy detection of spectrum holes based on diverse spectrum sensing techniques [5], [6]. Reliable broadband communication in longer interval symbols permit by OFDM while separating a high data rate streams into abundant low data rate streams [7].

Due to use of FFT/IFFT, strictly spaced narrowband orthogonal subcarriers, OFDM offer vast flexibility, and adaptability to diminish ISI on time varying multipath fading channel. It also permits dynamic allocation of spectrum holes efficiently [8]. Decrement in capacity due to subcarrier cancellation [9], [10] in OFDM based CR can be compensate with MIMO [11], [12]. Multiple transmit antenna offer enhanced beam forming and multiple receive antenna used for superior directivity [13]. This hybrid techniques MIMO-OFDM based CR present significant enhancement in system capacity and diversity gain with flat fading channel [14]. In order to attain same capacity, MIMO system need low transmit power in comparisons of SISO [15]. As we have to take full advantage of capacity of CR system in downlink with interference constraint of PU as well as restriction on maximum transmit power of SU, in this paper waterfilling mechanism have been put into operation with CSI. When channel information obtained through training sequence or pilot from PU, is known as waterfilling approach which can improve system capacity [16] [17]. Since, it allows proper allocation of power to each subchannel instead of allocating equal amount of power to each subchannel in the absence of channel information [18].

The paper is organized as follows: Section 3 describes various spectrum sharing approaches. System model for MIMO-OFDM based CR proposed in section 2. Mathematical expression and theoretical explanations for optimal power allocation is presented in Section 4. In Section 5, simulation results have been demonstrated and finally the conclusions are drawn in Section 3.

2. SPECTRUM SHARING APPROACHES

In order to afford concurrent existence of primary users (PU) and secondary users (SU), it is suggested that SU should have adequate information about its adjoining environment and operating parameters in which it is working. Based on congregate information that is obligatory for SU to operate in a network, where PU already being used, therefore interference constraint subsists. As shown in Fig.1, spectrum sharing approach can be categorize as underlay approach, overlay approach, and interweave approach. Following approaches used to exploit under-utilized and unused spectrum in a DSA mechanism [19], [20].

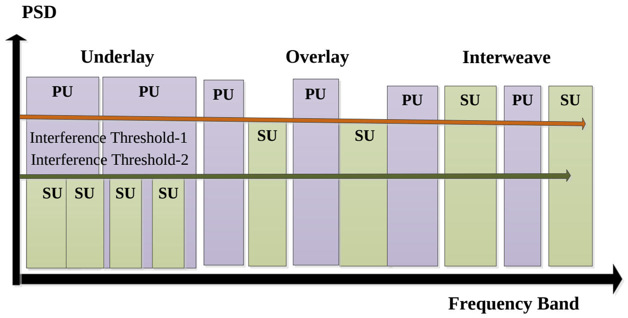

Fig.1. Various Spectrum Sharing Mechanisms in CRN

Underlay approach worn to prevail over under-utilized spectrum, where primary and secondary users can operate simultaneously till interference bound at primary receiver remain tolerable and not go beyond certain threshold. When both types of users subsist in same spectral regions, although transmission by secondary users is underneath threshold, interferences arise due to coexistence [21]. Underlay approach is more conformist choice as it permits transmission at low power so that interference limits of primary not surpass predefined range. Due to low power transmission, it supports shorter range and lower data rate applications. A different approach identified as overlay utilizes unused spectrum. Here PUs and SUs exist in side by side band in supportive manner. So SU acquire information from PU that applied to prevail over interference and offers enhanced performance at primary by relaying. In swap, primary user may enlarge limit of interference. Superior performance attain in overlay approach as it involve high degree of collaboration between PUs and SUs. Due to side by side existence, interference occur when orthogonality lapse [22]. It's matter-of-fact from existing literature that under certain interference constraint, SU can transmit larger amount of power in overlay approach if compare with underlay approach [15], [16]. Interweave approach where SUs have to supervise and discover under-utilized spectrum band to use efficiently and set up communications in opportunistic manner. SUs can access vacant spectrum only when PUs are not active. When nature of PUs is dynamic, spectrum holes detection becomes more exigent task. Due to such issues more agile in switching of frequency band required by SUs.

During power allocation in overlay approach, entire power is allocated to those subcarriers which falls in unused PU band, with this transmission rate can be improved but chances of poor channel quality is always there. Supplementary side in underlay approach, power allocated to subcarrier which falls in underutilized engaged band of PU, although having superior channel quality but experience more interference to PU band [23]. Similarly interweave approach permit spectrum access to SU only when PUs is not in operation. Distinct issue of unused or under-utilized spectrum band can be overcoming with above mentioned techniques. But in order to sort out aforementioned issues together, lots of researches are going on joint or hybrid approach to provide efficient resource utilization with optimal power and subcarrier allocation with maximizing capacity [24]–[26].

3. PROPOSED SYSTEM MODEL

In our system model we have consider downlink case for SU where both primary and secondary users coexist. Perfect channel state information between SU Tx and SU Rx as well as SU Tx and PU Tx are available through user and sensing channel respectively.

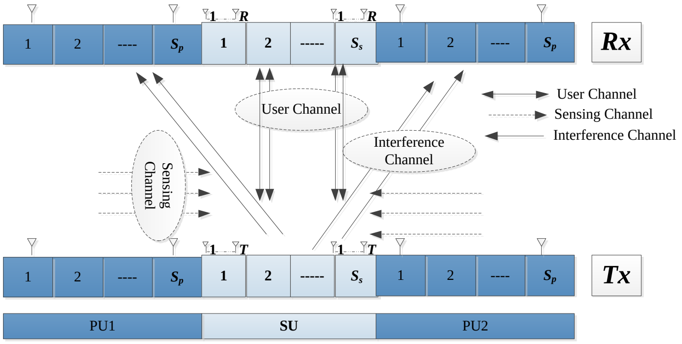

Fig.2. System Model for MIMO_OFDM based CRN

Following are the parameters used in illustration:

S_p - Number of subcarrier at PU.

S_s - Number of subcarrier at SU.

T - Number of transmitting antenna for each subcarrier at SU.

R - Number of receiving antenna for each subcarrier at SU.

$I_{threshold}$ - Interference threshold, which is maximum amount of interference power that can be tolerated at PU.

$p_{i,j}$ - Transmit power at j^{th} antenna of i^{th} subcarrier.

$\sigma_{i,j}$ - Singular value of MIMO channel matrix of SU.

σ_0 - AWGN variance.

$h_{i,r,t}$ - Channel gain between r^{th} receive antenna and t^{th} transmit antenna.

$g_{i,j,t}$ - Channel gain between t^{th} transmit antenna of SU and j^{th} PU Rx corresponding to i^{th} subcarrier of SU.

T_s - OFDM Symbol duration.

d_{ik} - Spectral separation between i^{th} subcarrier at SU and k^{th} subcarrier at PU.

Δf - Spectral distance between adjacent subcarrier.

4. OPTIMAL POWER ALLOCATION USING WATERFILLING APPROACH

Waterfilling approach is similar as pouring the water in vessel, where total amount of filled water i.e., allocated power value is proportional to the SNR of channel. To maximize channel capacity, it allows optimal distribution of total transmit power among various number of channels.

General capacity of MIMO system is given as:

$$C = \sum_{1}^{N} \log_2 \left(1 + H\left(\frac{T_T + I_{oG}}{C} \right) - I_{iG} \right) \tag{1}$$

where,
N - Number of Channel
T_T - Total Transmit Power
I_{oG} - Inverse Overall Channel Gain
C - Sum of Channel
I_{iG} - Individual Inverse Channel Gain

General Steps of Algorithm:

Step 1: Specify total transmit power for subcarriers and noise power to each channel corresponding to each subcarrier.

Step 2: Compute area for water filling while summing of total amount of power and inverse of overall channel gain.

Step 3: In order to decide initial water level, compute average allocated power.

Step 4: Subtract inverse channel gain of individual channel with average allocated power which gives amount of power allocated as Power=max (0, Power) to each sub channel.

Step 5: To maximize capacity with constraint on power and resource, use Lagrange function and get solution of optimization problem.

MIMO channel matrix between SU Tx and SU Rx is given as below [25]:

$$H = [H_1, H_2, H_3, \ldots, H_i] \tag{2}$$

where,

$$H_i = \begin{bmatrix} h_{i,1,1} & \cdots & h_{i,1,t} \\ \vdots & \ddots & \vdots \\ h_{i,r,1} & \cdots & h_{i,r,t} \end{bmatrix}$$

Each subcarrier with $R\times T$ dimension matrix. Channel matrix between SU Tx and PU Rx given as:

$$G_{i,j}=[g_{i,j,1},g_{i,j,2},g_{i,j,3},\ldots,g_{i,j,t}] \tag{3}$$

Due to perfect CSI at SU Tx, each subcarrier channel can be decomposed into parallel independent sub channel using singular value decomposition (SVD) method [27]. Singular values of channel matrix on each subcarrier are assigned as channel gain to each sub channel.

$$H_{R\times T}=U\varepsilon V^H \tag{4}$$

where,

$$U_{R\times T} = [U_1, U_2,U_3,\ldots,U_T]$$

$$\varepsilon_{T\times T} =$$

$$V_{T\times T}^H = \begin{bmatrix} V_1^H \\ \vdots \\ V_T^H \end{bmatrix}$$

Property of singular values such that

$$\sigma_1\geq\sigma_2\geq\sigma_3\ldots\sigma_T\geq 0$$

Capacity of i^{th} subcarrier of SU:

$$C_i = \sum_{j=1}^{\min(T,R)} \log_2\left(1+\frac{\left(p_{i,j}\right)\left(\sigma_{i,j}\right)^2}{\sigma_0}\right) \tag{5}$$

Due to orthogonality among subcarriers at SU, data transmission with OFDM is free from ISI. But it can be interfere with PU, because PU is not bounded to use OFDM. Such interference on PU depends on transmit power of SU as well as distance between SU subcarrier with PU.

Interference on PU due to SU given as [24]:

$$I_{i,j}\left(d_i, p_{i,j}\right) = p_{i,j}T_s \int_{d_{ik}-\Delta f}^{d_{ik}+\Delta f} \left(\frac{\sin \pi T_s f}{\pi T_s f}\right)^2 df$$

In order to achieve our objective to allocate power in such a way that maximize capacity of SU under interference constraint imposed by PU and maximum transmit power constraint at SU. Objective function for maximum achievable system capacity of SU can be written as [28]:

$$C_{\max} = \sum_{i=1}^{S_s}\sum_{j=1}^{\min(T,R)} \log_2\left(1+\frac{\left(p_{i,j}\right)\left(\sigma_{i,j}\right)^2}{\sigma_0}\right) \tag{6}$$

Subject to following interference and power constraint:

$$\sum_{k=1}^{S_p}\sum_{i=1}^{S_s}\sum_{j=1}^{\min(T,R)} I_{i,j}^2\left(d_{i,j}, p_{i,j}\right) \leq I_{threshold} \tag{7}$$

$$\sum_{i=1}^{S_s}\sum_{j=1}^{\min(T,R)} p_{i,j} \leq P_T \tag{8}$$

$$p_{i,j} \geq 0 \tag{9}$$

To get solution for optimal power allocation, apply Lagrange multiplier with KKT method [29] in Eq.(6) which will give result as:

$$p_{i,j} = \left\{ \frac{1}{\alpha \sum_{k=1}^{S_p} \frac{\partial I_{i,j}^k}{\partial p_{i,j}} + \beta_{i,j}} - \frac{\sigma_{i,j}^2}{\sigma_0} \right\}^+ \tag{10}$$

where,

$\{Z\}^+$=max(0,Z) and α, β and γ are Langange multipliers, can be obtained using above mentioned various constraint in Eq.(7), Eq.(8) and Eq.(9) given as:

$$\alpha \sum_{k=1}^{S_p} \frac{\partial I_{i,j}^k}{\partial p_{i,j}} + \beta_{i,j} = \frac{1}{\frac{\sigma_0}{\sigma_{i,j}^2}} + \gamma_{i,j} \tag{11}$$

$$\beta_{i,j}\left(\sum_{i=1}^{S_s}\sum_{j=1}^{\min(T,R)} p_{i,j} - P_T\right) \geq 0 \tag{12}$$

$$\gamma_{i,j}\, p_{i,j}=0 \tag{13}$$

For conventional MIMO-OFDM, where first total amount of transmit power have been calculated using uniform allocation under predefined threshold. Then equal power will be assigned to each subcarrier given as [26]:

$$p_i = \frac{I_{threshold}}{S_s \sum_{i=1}^{S_s}\sum_{k=1}^{S_p} \frac{\partial I_i^k}{\partial p_i}} \tag{14}$$

For conventional OFDM, optimal power allocates to each subcarrier as [23]:

$$p_i = \left\{\left(P_T + \sum_{i=1}^{S_s} \frac{\sigma_0^2}{\sigma_i}\right) - \frac{\sigma_0^2}{\sigma_i}\right\}^+ \tag{15}$$

5. SIMULATION RESULT AND DISCUSSION

Simulation to observe performance and effectiveness of proposed approach, MATLAB has been used as software tool and simulation parameters given in Table.1.

Table.1. Simulation Parameters

Name of Parameter	Value
Number of Sub channel	(16,32)
Total transmit power	-20dBm; 30dBm
Total available bandwidth	1MHz
Noise density	-80 dBm, -90 dBm
Symbol duration	4e-6 s
No. of PU users	2
No. of SU users	1

Assume knowledge of perfect CSI that will be used to allocate subcarrier and power at SU transmitter. A MIMO-OFDM based cognitive radio system with S_s and S_p number of subcarriers at SU and PU respectively. MIMO channel matrix with dimension $R \times T$, where number of transmit and receive antennas denoted by T and R respectively.

The Fig.3 shows conventional waterfilling approach for OFDM as given in Eq.(15) where subcarrier with good channel, assigned by larger amount power and subcarrier with bad channel not assigned power.

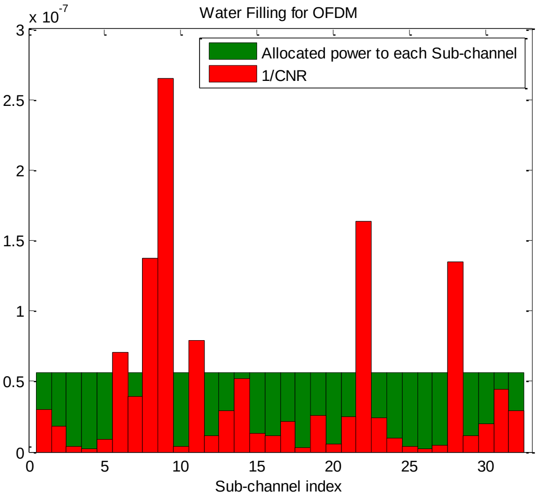

Fig.3. Conventional water filling for OFDM

Power allocation in OFDM based CR given by ladder type profile. In order to minimize interferences that can occur by SU to PU due to coexistence. To do the same, assigning minimum or no power to subcarrier of SU those are nearer to PU and subcarrier with far distance from PU or having less chance of interfering with PU, allocate more power as depicted in Fig.4. As issues related to unused and under-utilized spectrum band can be overcome while considering hybrid sharing with underlay, overlay and interweave approach.

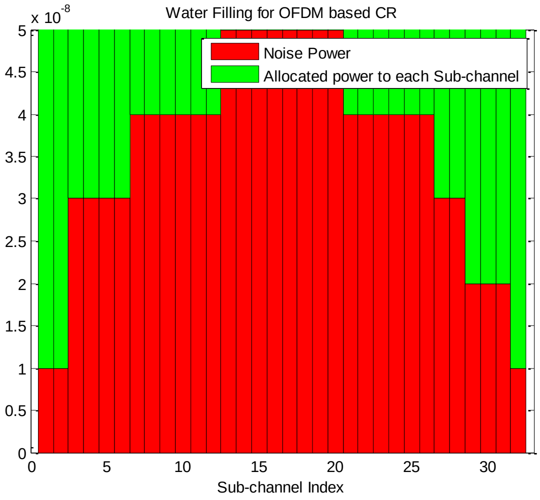

Fig.4. Water filling for OFDM based CR

The Fig.5 shows result for simulation of hybrid sharing scenario. Here we represent total number of SU's subcarriers into four different zones such as restricted zone in which transmission not allow from SU in any case.

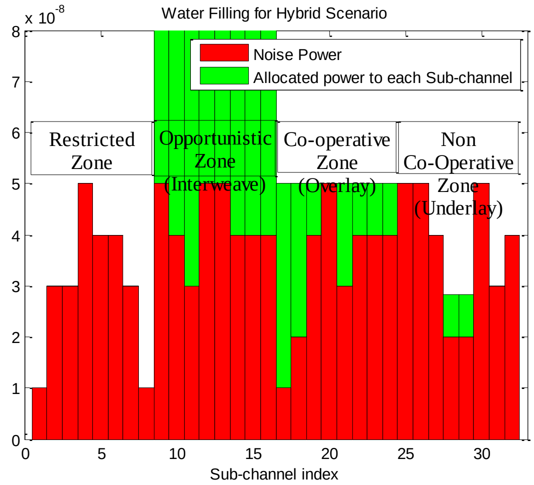

Fig.5. Water filling for hybrid scenario

Another one is interweaving zone, where SUs has to detect under-utilized spectrum band to allocate available resource efficiently and set up communications in opportunistic manner. As both PU and SU coexist in side by side band but SUs can access vacant spectrum only when PUs are not active. Next is cooperative zone allows existence of PUs and SUs in alternate band in supportive manner. So SU get channel state information from PU that applied to prevail over interference and offers enhanced performance at primary by relaying. In swap, primary user may offer interference threshold-2 greater than interference threshold-1 as shown in Fig.2.

Superior performance attains in overlay approach as it involve better cooperation between PUs and SUs. Last one is non-cooperative zone corresponding to underlay approach, where primary and secondary users can operate simultaneously till interference bound at primary receiver remain tolerable and not go beyond certain interference threshold-1.

To maximize channel capacity, it allows optimal distribution of total transmit power among various number of channels in all the cases. In order to achieve our objective to allocate power in such a way that maximize capacity of SU under interference constraint imposed by PU and maximum transmit power constraint at SU expression derived in Eq.(10) used for simulation result.

6. CONCLUSION

It has been shown that individual underlay or overlay approach can't resolve both issues as unused spectrum and underutilized spectrum related to efficient utilization of available resource. Therefore hybrid scenario has been proposed in this paper for spectrum sharing and optimal power allocation for MIMO- OFDM based CRN have been illustrated using water filling approach accordingly. Through the simulation results, water filling approach for MIMO-OFDM based CRN with spectral distance between SU to PU subcarriers and other one with hybrid sharing scheme, have been evaluated..

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