ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 12, December 2014

Subcarrier and power allocation in OFDM based cognitive radio networks: A Survey

VIDHYA.B[1], RAMYAH.S.B[2], REVATHI.G[3]

PG Student, Dept., of ECE , School of Communication and Computer Sciences, Kongu Engineering College, India[1,2,3]

Abstract: This paper investigates the subcarrier and power allocation problem for an OFDM-based cognitive radio (CR) system. For CR systems it is important to keep the interference below the certain threshold to the primary user and the total power allocated to the CR user under a constraint . Since the joint subcarrier and power allocation problem is a non-convex integer problem and a closed form solution is difficult to find, a optimal and suboptimal algorithm that separates subcarrier and power allocation is investigated. The suboptimal subcarrier algorithm is proposed that allocates subcarriers to CR users that not only increase the transmission rate, but also reduces the interference introduced to the primary user (PU) band. Comparison results show that for CR systems the proposed algorithm is able to load power into the subcarriers while keeping the interference below a specified threshold.

Keywords: Cognitive radio, OFDM, Subcarrier allocation, Power allocation

I. INTRODUCTION

Cognitive radio(CR) [1] is an intelligent wireless radio that is aware of its surrounding environment and detects the available channels in the spectrum and accordingly changes its parameters to allow wireless communication in a given spectrum band at one location. Cognitive radio has been considered as a key technology for future wireless communications and mobile computing. It offers great promise for improving the system efficiency and a spectrum utilization. The allocated spectrum bands are not utilized efficiently and in particular there are two spectrum usage scenario have been considered.

First is the unused one i.e. the spectrum has been licensed but is not currently being occupied in a given geographical area. The second is the underused one i.e. the spectrum is allocated and not used to its full capacity.

In a wireless network where both the primary system and the secondary system employ OFDM transmission technology, the SUs can flexibly fill the spectral gaps left by the PUs [2] or transmit over the unused subcarriers left in the primary system [3]. Even if there are no unused subcarriers left in the primary system, SU can flexibly share the subcarriers with PUs on condition that PUs are sufficiently protected [4]. Orthogonal Frequency Division Multiple (OFDM) technology [5] is considered as a best modulation technique for CR system. In an OFDM system, the frequency band is divided into a large number of subchannels that use specific frequencies so as to be completely orthogonal to each other, which not only reduce the mutual interference between the subcarriers, but also improve the spectral efficiency. However, OFDM signals have high spectral leakage, resulting in strong interference to LUs in CR system. Therefore, the total interference introduced to the PU band and the total power allocated to the CR users should be taken into account during the resource allocation.

To improve the transmission capacity of the CR users and to reduce the interference to the PUs several subcarrier and power allocation methods are employed. There are two types of interference occur between the PU and the CR users. One due to the secondary users to the PUs and the second one is due to the PUS to the cognitive radio(CR) users. There are some interference constraints to improve the transmission rate of the CR users.

If the cognitive radio finds the spectrum is free i.e. the spectrum is not currently used by the primary users that vacant spectrum is divided into OFDM subcarriers. Each subcarrier is allocated to one particular user but one user can occupy more than one subcarrier. Allocation of power to the subcarriers is based on the channel gain and the spectral distance between the ith subcarrier and the PU band. This paper explains how the subcarriers are allocated to the users and power allocated to each subcarrier and fairness improvement. The PU occupies a bandwidth and the CR users occupy the adjacent band to the PU band. There are two types of scenario one is underlay spectrum access mechanism(USAM) and another is overlay spectrum access mechanism(OSAM) . In USAM, PUs and the CR users coexist in the sane spectral band. In OSAM, secondary users and the PU coexist in the side-by-side bands. Mutual interference between the secondary users and the primary users occur due to the non-orthogonality of the transmitted signals in OFDM based CR system. In order to limit the interference to the secondary user within the range that the primary user can tolerate, the secondary user must control its transmission power according to the interference threshold. In this several subcarrier and power allocation methods are investigated and also the joint subcarrier and power allocation methods are reviewed.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Consider a cognitive radio access model as shown in Fig.1 [3], where the frequency band B occupied by the primary user is shown and the frequency band for the secondary users are shown in the middle and they are subdivided into N subcarriers each having a bandwidth of Δf Hz. The unoccupied bands sensed by the CR is located on both sides of the primary user band. The interference introduced to the primary user by the CR user depends on the spectral distance between the ith subcarrier and the PU band and the power allocated to the secondary users. To maximize the transmission rate of the CR users while maintaining the interference below the certain threshold level. Assuming the channel gain $h_{k,n}^{ss}$, $h_{k,n}^{sp}$, $h_{k,n}^{ps}$ are known at the CR user transmitter.

$h_{k,n}^{ss}$ - channel gain between the CR user's transmitter and the CR user's receiver for the i^{th} subcarrier

$h_{k,n}^{sp}$ - channel gain between the CR user's transmitter and the l^{th} PUs receiver

$h_{k,n}^{p}$ - channel gain between the l^{th} PUs transmitter and the CR user's receiver

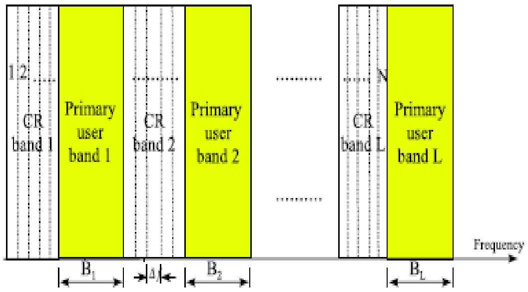

Fig:1 Distribution of CR and Primary users in frequency domain[3]

The total transmission rate for the i^{th} subcarrier, transmit power P_i and the channel fading gain is related by the Shannon capacity formula given as (Eq 6) in [4].

Cognitive radio senses the spectrum using spectrum sensing methods and finds the vacant spectrum. The vacant spectrum is utilized by the secondary users and interference occur between the primary users and secondary users. If the primary user and CR user both access the same spectrum, interference causes capacity of the primary user. The interference is mainly caused by the sidelobes of the OFDM signal. The power density spectrum of the i^{th} subcarrier by assuming the ideal Nyquist pulse shaping at the CR transmitter is given as [5].

$$\phi_i(f) = P_i T_s \left(\frac{\sin \pi f \, \mathrm{Ts}}{\pi f \, \mathrm{Ts}}\right)^2 \qquad \text{(eq 1)}$$

P_i – Total transmit power in the i^{th} subcarrier

T_s – Symbol duration

Now the interference introduced by the CR user to the primary user is given by the integration of the power density spectrum of the i^{th} subcarrier across the l^{th} primary user band. This interference is denoted by $I_i^{(l)}(d_{il},P_i)$ and given by

$$I_i^{(l)}(d_i^{\,l},P_i)=(h_l^{s,p})^2 P_i T_s$$

$$\int_{\mathrm{dil}-\mathrm{Bl}/2}^{\mathrm{dil}+\mathrm{Bl}/2} \left(\frac{\sin\pi f \, \mathrm{Ts}}{\pi f \, \mathrm{Ts}}\right)^2 \, df \qquad \text{(eq 2)}$$

where d_{il} represents the spectral distance between i^{th} subcarrier of CR user band and the l^{th} PU band. B_l represents the bandwidth occupied by the primary user. Then considering the another type of interference introduced to the secondary by the primary users. After performing Fast Fourier Transform, the power density spectrum can be expressed by the expected value of the periodogram. This gives the interference introduced to the secondary users by the primary users. Refer (eq 5) in [3]. In that equation, ω represents the frequency normalized to the sampling frequency and $\varphi_{PU}^{e^{j\omega}}$ is the power density spectrum of the PU signal. In this, to improve the quality of service(QoS) of cognitive radio users, several methods were discussed.

III. SUBCARRIER ALLOCATION

Subcarrier allocation is the main aspect in power allocation. Subcarrier allocation in cognitive radio OFDM system should be carried out with consideration about the Signal-to-Noise Ratio (SNR) , quality of the subchannel and the interference introduced to the PU band. This subcarrier allocation is based on maximum achievable rate of each subcarrier. This explains how the subcarriers are allocated to each user and there are several methods in allocating the subcarriers as in [11]. First, the subchannel is always allocated to the SU who can obtain the maximum transmission rate. Then, the left subchannels are allocated to the CR users who suffers the severest unjustness. The capacity of the CR when it transmits through a particular subcarrier depends on the channel gain of the user.

The complexity of the subcarrier allocation method is O(KZ) where K is the number of cognitive radio users and Z represents the total number of subcarriers. In a system with K users and Z subcarriers, there are K^Z subchannel allocations, since it is assumed that no subcarrier should be occupied by more than one user. Assign subcarriers to each user to satisfy the minimum rate constraints. This can be achieved by minimizing the sum power allocated to the user. Consider another case, that it involves both the underlay and overlay subcarrier allocation to improve the transmission rate of the CR users. The underlay subcarriers may introduce higher interference compared to the overlay subcarriers. The channel quality of the underlay subcarriers is high compared to the overlay subcarriers.

III.A Subcarrier allocation methods

The maximum rate subcarrier allocation method aims to increase the transmission rate of the CR users. In this cognitive radio networks, subcarrier allocation is given by

$$k = \arg\max \frac{|h_{k,n}^{ss}|^2}{\sigma 2+\sum_{l=1}^{L} J_{k,n}^{(l)}} \qquad \text{(eq 3)}$$

This method will increase the transmission rate of the CR users. To minimize the interference introduced to the PU minimum interference subcarrier allocation method is used. Since the PUs and the CR users exist in side by side bands, the interference to the PU should be minimum as possible. The fair rate subcarrier allocation method is to achieve fairness among the secondary users. Here the capacity of the cognitive radio users is taken in consideration. In this, the channel fading gain is assumed to be 1 db and the bandwidth of the primary user is 1 MHz. The drawback of this method is that it increases the cost of the capacity of the CR users when fairness is taken into account. To overcome this, optimal and suboptimal methods are used.

In random subcarrier allocation method[13], no spectrum sensing is involved and due to the lack of information about the primary user activities CR user randomly allocates the subcarriers. The interference that causes onto PU is controlled by adjusting the transmission power belo the certain threshold. To avoid this interference, [13] paper proposed an effficient centralized sequential algorithm based on opportunistic scheduling in order to ensure the orthogonality of subcarriers. The drawback of this method is that when multiple SU randomly allocates the subcarrier, it will cause drastic performance degradation.

III.B Optimal and suboptimal subcarrier allocation methods

In this, the goal is to maximize the total transmission rate of the CR user hence allocate a particular subcarrier to a CR user that exhibits a high signal-to-interference plus noise ratio. The optimal method is given as (eq 13) in [8].Using this method, the CR user with better channel quality will enjoy better transmission rate. For practical sytem, it is not desired therefore suboptimal algorithm is proposed to improve the fairness to certain amount of overall transmission rate. This method will degrade the fairness performance of individual CR user data rate. To maintain a certain level of fairness, the ratio among the transmission rate of CR users is to be maintained. It is given by

$$R_{1:}\ R_{2:\ldots:}\ R_k = ß_{1:}\ ß_{2:\ldots:}\ ß_k \qquad \text{(eq 4)}$$

where R_u represents the transmission rate achieved by the uth user and $ß_u$ is a positive constant.

In order to satisfy lth interference constraint power is allocated according to ladder profile as in [7]. It is based on the heuristics that if a subcarrier is closer to a PU band, it introduces more interference. Hence, less power should be allocated to that particular subcarrier. In particular, we propose to allocate power in each CR subcarrier such that the allocated power is inversely proportional to the factor (l) i that depends on the spectral distance between ith CR subcarrier and the lth PU band. This method achieves better performance compared to optimal and classical methods. According to [8], the fairness performance in terms of data rate sharing of the individual CR user for the optimal method is poor. Therefore, low complexity suboptimal subcarrier allocation method is employed to improve the fairness rate.

IV. POWER ALLOCATION METHODS

After the subcarriers are allocated to the specified users, power should be allocated for each subcarrier based on some constraints. To exploit the time-varying nature of the fading gains across the OFDM subcarriers, power loading algorithms are used. As [4], the power loading scheme maximizes the transmission rate of the CR users. The design of power allocation strategies for the secondary user fading channel under the constraint on the maximum acceptable PU transmission outage probability is considered. The power must be allocated in the subcarriers uniformly such that the total interference will be below the threshold value.

IV.A Waterfilling algorithm

In this waterfilling method [4], power is allocated according to the channel gain of the subcarrier. In this classical waterfilling method, more power is assigned for subcarriers which exhibit higher channel gain and less power for subcarriers with low channel gain. This method for allocating power to subcarriers in OFDM systems is not suitable for CR systems because it does not taken the consideration of the protection of the PU. The interference introduced by this waterfilling method will not be equal to interference threshold. The drawback of this method is that subcarriers will be assigned to higher power levels which in turn cause severe interference to the adjacent PU. The waterfilling scheme can be given as (24) in [4]. The uniform power loading algorithm overcomes the drawbacks of waterfilling algorithm.

IV.B Uniform power loading algorithm

In this uniform power loading algorithm, equal amount of power is allocated in each subcarrier which is used in conventional OFDM systems due to its reduced complexity. Assuming equal amount of power in each subcarrier and solving the equation given as eq (9) in [7]. The corresponding for the ith subcarrier is given by

$$P_i^{(l)} = \frac{I_{th}^{(l)}}{2\sum_{i=1}^{N} K_i^{(l)} \lambda_l^2 \, ln\frac{1}{1-a}} \forall l \qquad \text{(eq 5)}$$

The uniform power loading schemes has low complexity but the performance of this algorithm is poor compared to other schemes. In order to improve the performance several optimal methods are employed.

IV.C Optimal method

The main objective of optimal method is to maximize the transmission rate of the CR user while keeping the interference to the primary user to a certain threshold. Using Lagrange's coefficients which can be calculated using Newton's method, the optimal power can be allocated to the CR user. An optimal scheme is highly complex and there are several iterations required to calculate the value of λ. Instead of using the interference power constraint(IPC) to protect the primary users, a new constraint namely rate loss constraint(RLC) is considered. As given in [11], CR system achieves maximum transmission rate compared to IPC. It was shown that the proposed power allocation scheme obtained under the rate loss constraint can achieve substantial rate gains over the conventional power allocation scheme obtained under the interference power constraint.

The Newton's method can be used to find the Lagrange parameters in a quadratic complexity. As the complexity is quite high then we go for low complexity suboptimal power allocation method. In this scheme, the power is allocated so that the subcarriers that are adjacent to the primary user bands are given power p. and the power is increased by p as one subcarrier moves away from the primary user bands. Hence, the power p will be assigned to subcarriers that are adjacent to the primary user bands. To those right next to the primary user bands, we allocate 2p, and so on. Hence to maximize the capacity, power should be maximized. The complexity of this optimal scheme is O(N logN). In order to reduce the complexity, suboptimal schemes are introduced to improve the transmission rate of the secondary users. As represented in [7], if the power budget increases the interference becomes dominant and the transmission rate of the CR user does not get increased.

IV.D Suboptimal method

In the suboptimal method, the power is allocated according to the ladder profile[3]. In this power is allocated based on the fact that if the subcarrier is closer to the PU band it produces more interference. Hence less power should be allocated to that subcarrier.

In the suboptimal method, two types of CR user bands are considered. One is adjacent to the one PU band and the other is surrounded by PU bands on both sides. Then the power allocated to nearby subcarriers suggests that power is distributed like a single ladder profile in CR band 1 and the step ladder profile for other CR user subcarriers. This method will allocate the power to each subcarrier such that the total power is inversely proportional to K_i^l . The allocated power in the i^{th} subcarrier because of the l^{th} interference constraint is given as[7]

$$P_i^l = \frac{P}{K_i^l} \forall l \qquad \text{(eq 6)}$$

The total transmit power is calculated such that the total interference introduced by all subcarriers is equal to the interference threshold. The subcarrier which is adjacent to the PU band is allocated with a power of P and propose to allocate power 2P to the next closest subcarrier.

The suboptimal scheme provides faster operation compared to optimal scheme. The suboptimal method outperforms the uniform power loading and the optimal method. The complexity of the suboptimal method is O(1).

V. JOINT SUBCARRIER AND POWER ALLOCATION METHOD

In this, the joint subcarrier and power allocation methods are considered. In wireless communication systems, the fairness is a very important factor that should be considered for allocating radio resource to multiple users . In this section[9], we design a novel algorithm of jointing subcarrier and power allocation to achieve the performance tradeoff between fairness and system capacity. For multi-user OFDMA systems, several users share discrete Subcarriers and at that time one user is allowed to transmit power on each subcarrier. There are two considerations first one is to minimize the total transmission power subject to the quality of service (QoS) constraint and the second is to maximize the capacity of the system. The joint subcarrier and power allocation scheme aims to increase the throughput of all secondary transmissions while satisfying some constraints on maximum interference to PUs. Lagrange method is used to obtain the optimal method. A fairness indicator is defned to evaluate various subcarrier allocation schemes.

Optimal power allocation scheme offers better performance than the other three suboptimal schemes, and the fairness based subcarrier allocation scheme provides the best performance tradeoff between fairness and capacity in a cognitive radio network.

In paper [12], they considered the joint subcarrier and power allocation method based on weighted sum-rate maximization in uplink OFDMA systems. Suboptimal schemes has shown better performance in fairness and achieves near optimum performance. This method gives less complexity but an efficient one. Consider the another case overlay and underlay subcarrier and power allocation as [8], this joint overlay and underlay spectrum access mechanism not only achieves higher transmission rate but also the transmit power. Some underlay subcarriers have relatively better channel quality between the CR transmitter and the CR users, and the subcarriers overlap with the PU receivers that experience poor channel quality from the CR transmitter. This JOUSAM requires less transmit power while achieving a higher transmission rate compared to other methods.

VI.NUMERICAL RESULT ANALYSIS

In all these considerations, symbol duration is taken to be $T_s = 4\ \mu s$ and the bandwidth of each subcarrier is assumed to be 0.3125MHz. The channel power gain is assumed to be 10 db. Using these values, the transmission rate of the

CR user is maximized. The channel fading amplitude gain is assumed to be Rayleigh distributed.

In all these constraints, it is assumed that the channel gain is known at the CR transmitter but it is not always possible for the CR transmitter to know the instantaneous values of channel gains. Future Power loading schemes are employed to develop this scheme when channel gain is not known at the CR transmitter.

PARAMETERS	OVERLAY	UNDERLAY	OPTIMAL JOUSAM	SUBOPTIMAL JOUSAM
	OPTIMAL OSAM	OPTIMAL USAM		
Transmission rate	6.5 Mbps	7.2 Mbps	11.5 Mbps	10.3 Mbps

Table I: Transmission rate for subcarrier and power allocation methods

PARAMETERS	WATERFIILING METHOD	UNIFORM LOADING SCHEME	OPTIAL SHCEME	SUBOPTIMAL SCHEME
Transmission rate	5.2 Mbps	4.2 Mbps	13.8 Mbps	5.8 Mbps

Table II: Transmission rate for joint subcarrier and power allocation methods

Channel gain= -52.39db

Interference threshold = $12*10^{-13}$Watts

VII. CONCLUSION

Cognitive radio technology mainly deals with power allocation of secondary users. In order to reduce the interference and improve the quality of service to the CR users, the various subcarrier and power allocation strategies are reviewed as transmission rate constraints. The optimal schemes exhibit a high transmission rate but are high complexity. Several suboptimal schemes are analyzed and their complexity is low but achieves transmission rate close to optimal schemes. In future work, this can be further improved by maximizing the transmission rate and fairness by considering joint overlay and underlay spectrum access mechanism.

REFERENCES

[1] S.Haykin, “Cognitive radio:brain-empowered wireless communications,” Selected Areas in Communications,IEEE Journal on,vol.23,pp.201–220, Feb.2005.

[2] T.Weiss,and F.K.Jondral,“Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency,”IEEE Commun.Mag.,vol.43,no.3,pp.S8-S14,Mar.2004.

[3] T. Weiss, J. Hillenbrand, A. Krohn, and F. K. Jondral, “Mutual interference in OFDM-based spectrum pooling systems,” in *Proc. IEEE VTC*, Milan, Italy, May 2004, vol. 4, pp. 1873–1877.

[4] G. Bansal, Md. J. Hossain, and V. K. Bhargava, “Optimal and suboptimal power allocation schemes for OFDM-based cognitive radio systems,” *IEEE Trans. Wireless Commun.*, vol. 7, no. 11, pp. 4710–4718, Nov. 2008.

[5] P. Wang, M. Zhao, L. Xiao, S. Zhou, and J. Wang, “Power allocation in OFDM-based cognitive radio systems,” in *Proc. IEEE Global Telecommun. Conf. (Globecom)*, 2007, pp. 4061–4065.

[6] Q. Lu, T. Peng, and W. Wang, “Efficient multiuser water-filling algorithm under interference temperature constraints in OFDMA-based cognitive radio networks,” in *Proc. IEEE Int. Symp. Microw., Antenna,Propag. EMC Technol. Wirel. Commun.*, Hangzhou, China, Feb. 2007, pp. 174–177.

[7] G. Bansal, Md. J. Hossain, and V. K. Bhargava, “Adaptive power loading for OFDM-based cognitive radio systems with statistical interference constraint,” *IEEE Trans. Wireless Commun.*, vol. 10, no. 9, pp. 2786–2791, Sep. 2011.

[8] G. Bansal, Md. J. Hossain, and V. K. Bhargava, “Subcarrier and Power Allocation for OFDMA-Based Cognitive Radio Systems With Joint Overlay and Underlay Spectrum Access Mechanism,” *IEEE Trans. Vehicular Technology*, vol. 62, no. 3, March 2013.

[9] Lun Tang, Qianbin, GuanGyu Wang, Xiaoping Zeng, Huan Wang, “Opportunistic power allocation strategies and fair subcarrier allocation in OFDM-based cognitive radio networks,” Springer June 2011

[10] Xin Kang, Hari Krishna Garg, “Optimal Power Allocation for OFDM-Based Cognitive Radio with New Primary Transmission Protection Criteria,” IEEE Trans. On Wireless Communications, vol.9, no.6, June 2010.

[11] Shaowei Wang, Fangjiang Huang, Mindi Yuan and Sidan Du, “Resource allocation for multiuser cognitive OFDM networks with proportional rate constraints,” International Journal of Communication Systems, 2011.

[12] Mohammed Al-Imari*, Pei Xiao, Muhammad Ali Imran and Rahim Tafazolli, “Low complexity subcarrier and power allocation algorithm for uplink OFDMA systems,” EURASIP Journal on Wireless Communications And Networking, 2013.

[13] Sabit Ekin, Mohamed M. Abdallah, Khalid A. Qaraqe and Erchin Serpedin, “ Random Subcarrier allocation in OFDM based Cognitive Radio Networks,” IEEE Transactions on Signal Processing, vol.60, no.9, September 2012.

[14] E.D Kanmani Ruby, S Nithya, N Saranya “Effective Spectrum Sharing Method Using Power Allocation Algorithm In Cognitive Radio Networks” *Journal Of European Scientific*, Vol 10, Issue7, 2014.

[15] N Saranya, W Edwin Santhkumar, E.D Ruby “A Survey On Distributed Channel Selection Technique Using Surf Algorithm For Information Transfer In Multi-Hop Cognitive Radio Networks” *International Conference On Computational Science And Computational Intelligence (CSCI)* 2014, Vol 1, page 96-100,2014.

[16] S.Nithya, E. D. Kanmani Ruby, N.Saranya “Power Allocation Algorithm for Effective Spectrum Sharing Using in Cognitive Radio Networks” *Journal of International Scientific Forum*, Vol 3, Issue 1, pages 218-222, 2013.

[17] K Gomathi, D Leela, ED Kanmani Ruby “Spectrum Sensing Methods for Cognitive Radio” *International Journal of Communication and Computer Technologies*, Vol 02 – no.11 Issue: 2014, page 65-68, ISSN number: 2278-9723.