DOI: 10.21917/ijct.2020.0329

OPTIMAL POWER TRANSMISSION FOR VARIOUS SPECTRUM SHARING APPROACHES IN 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 context of effective resource utilization using spectrum sensing and dynamic spectrum access (DSA), Cognitive Radio (CR) has been proposed as versatile and an emerging technology. In order to understand, how OFDM is consider as suitable candidate for cognitive radio, this paper presents various aspects of Orthogonal Frequency Division Multiplexing (OFDM) based cognitive radio. As total transmission rate of CR user is maximized in interference constraint scenario, this paper also formulate problem for optimal transmit power control in OFDM based CR under various spectrum sharing approaches such as underlay, overlay and interweave. Apart from existing works in the literature here we presented mathematical formula for power-allocation schemes for interweave as well as joint underlay and overlay approach. MATLAB simulation shows that with optimal power transmission by CR users, capacity can be improved significantly.

Keywords:
Cognitive Radio, Overlay, Underlay, Interweave, Optimal Power

1. INTRODUCTION

A Due to conflict between spectrum scarcity [1], which occurs as number of wireless devices increasing rapidly and spectrum under-utilization [2] as most of the time major portion of spectrum remains unused, CR [3] [4] has been proposed as emerging technology where radio devices sense spectrum intelligently and access them dynamically to enhance utilization of precious resources. CR is acquainted about its operating environment as it's an intelligent system can sense spectrum and based on sensing information act accordingly on generated plans.

In recent trend, it has been observed that almost entire wireless technologies adapting OFDM for broadband as one of the potential candidate. Primary reason behind selecting multicarrier transmission approach as OFDM is that it provides highly flexible and adaptive physical layer, which is highly recommended for CR operation. As far as definition of CR concern, radio which is having better observations regarding sensing environment, tendency to adapt operating parameters in dynamic manner and intelligently can reach to a significant goal. Process which makes CR intelligent, can be understand by using cognitive cycle [5] formed by following states such as observe, orient, plan, decide and act.

Reliable broadband communication in longer interval symbols permit by OFDM while separating a high data rate streams into abundant low data rate streams. 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. 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. 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.

This paper is organized as follows: literature review has been presented in section 2. Section 3 describes merits and demerits of OFDM based CR networks along with its block diagram. Various approaches as overlay, underlay and interweave of spectrum sharing are explained in section 4. Problem formulations for optimal power allocation are given in section 5. Section 6 shows matlab simulation result of capacity versus signal to interference plus noise ratio (SINR) in joint scenario and interweave scenario. Finally, conclusions and future work are drawn in Section 7 and 8 respectively.

2. LITERATURE REVIEW

Number of literatures has presented OFDM as best suitable multicarrier approach for CR. Here we highlight few points out of them. Most important point is that OFDM provides efficient and effective techniques for modulation and flexibility in resource allocation, due to this reason prefer as potential candidate to CR networks [6].

One more key feature that creates positive impact to select OFDM is robustness and spectral efficiency at high data rate. Apart from these, other benefits of OFDM are its scalability and simple implementation as it involves Fast Fourier transform (FFT) [7].

In OFDM each symbols are loaded with subcarriers over a larger time duration which reduce interference caused by inter symbol commonly known as ISI. One of main function of CR is spectrum sensing and detection, where CR finds availability of spectrum holes in operating wireless environment. Due to FFT operation, OFDM simplify spectrum sensing in frequency domain. Another function of CR is Spectrum decision and management which will decide best available frequency unused band in order to maintain interference level and quality of services. In order to support this functionality, OFDM allows waveform shaping by simply carrier cancellations and windowing techniques [8].

Based on the quality of services, spectrum sharing and spectrum mobility allow allocating subcarrier for proper channel and transmitting power level accordingly. These approaches used to exploit unused and under-utilized frequency band in a dynamic spectrum access mechanism [9] [10].

3. OFDM BASED COGNITIVE RADIO

3.1 MERITS AND DEMERITS

Adaptive and scalable nature of OFDM system provides variation in FFT size, subcarrier spacing, size of cyclic prefix, modulation techniques, coding and power allocation in each subcarriers, which can enhance overall performance of CR networks. OFDM also supports simultaneous access to multiuser without any interference by assigning set of subcarriers orthogonally to different users.

When PU wants to use such bands which are currently occupied by SU, then SU has to be immediately moved into new band to provide uninterrupted services to PU.

In order to handle such cases, advanced antenna techniques such as multiple input and multiple output (MIMO) are commonly used with OFDM, which provide better beam forming and reduces complexity of equalizer.

3.2 BLOCK DIAGRAM OFDM BASED CR

OFDM based CR system block diagram as shown in Fig.1, represent interaction of various layers with cognitive engine [11]. Tasks of cognitive engine are allow to sense environment, plan and orient accordingly then act on final decision. In order to perform certain task and make CR so intelligent, cognitive engine consist decision unit, policy engine and local spectrum sensing unit. Based on the information received by policy engine and spectrum sensing unit, decision unit identify opportunity to make it intelligent and configure radio and its physical parameters. Physical layer parameters such as types of modulation, coding techniques, mode of transmission, operating frequency and patterns of interleave can be alter by changing configuration parameter of OFDM as well as also update functionalities of higher layer accordingly.

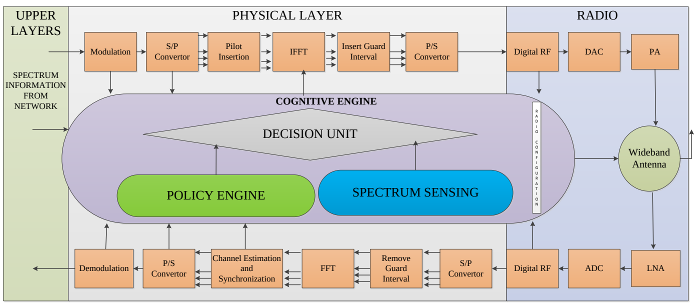

Fig.1. Block diagram of OFDM based CR System

4. UNDERLAY, OVERLAY AND INTERWEAVE - SPECTRUM SHARING APRROACH

In order to provide simultaneous existence of licensed users or PUs and cognitive or SUs, it is recommended that SU should have sufficient information about its surrounding environment and operating parameters in which it is operating. Based on gathered information, which are required to SU to operate in a network, where PU already being used, therefore interference constraint is also exist. Spectrum sharing approach can be classified into three categories shown in Fig.2, as underlay approach, overlay approach, and interweave approach.

As shown in Fig.2(a), underlay approach used to overcome under-utilized spectrum, where primary and SUs can work together until unless interference limit at primary receiver remain acceptable and not exceed with certain threshold value. As both type of users exist in same spectral regions, although transmission by SUs are below interference threshold, interferences occurs Another approach known as overlay exploit unused spectrum. As shown in Fig.2 (b), primary and SUs exist in side by side band in cooperative manner. SU gets information from pilot or training sequences of primary and applies it to overcome interference at primary as well as provides help to enhance performance of primary by relaying. In exchange, PU may extend limit of interference threshold. Better performance achieved in overlay approach as it requires high degree of cooperation between primary and SUs. As primary and SU exists side by side, there may be possibility of interference when orthogonally of transmitted signal not maintain [13].

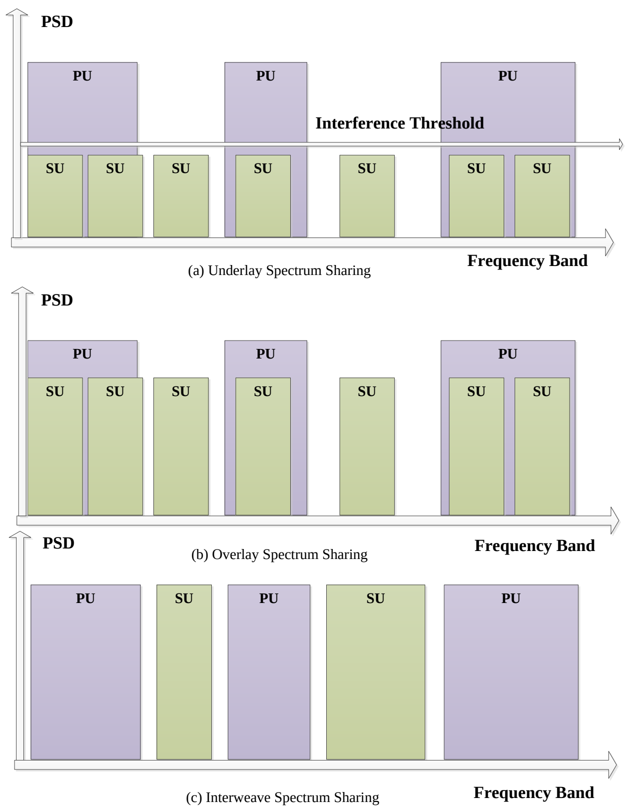

Fig.2. Various type of spectrum sharing in cognitive radio network

It have been observed from existing literature that under certain interference constraint imposed by primary, secondary transmitter can transmit larger amount of power for overlay in comparisons of underlay approach [14][15].

In case of Interweave approach as shown in Fig.2(c), SUs use spectrum holes in opportunistic manner which are left by PUs to establish communications. SUs have to monitor and identify under-utilized frequency spectrum band which can be used by unlicensed user. SUs are allowing to access available spectrum only when PUs are not active. Detection of spectrum holes becomes more challenging task when nature of PUs is dynamic. Due to following issues more agile in switching of frequency band required by SUs.

Single issue related to either unused spectrum or under-utilized spectrum band can be mitigating by using above mentioned techniques. While allocating power in overlay approach, complete power is allocated to that subcarriers which falls in unused PU band, so transmission rate can be enhanced but there may be chances of poor channel quality. On the other side in underlay approach, power allocated to subcarrier which falls in underutilized occupied band of PU, although it have better channel quality but experience more interference to PU band. Similarly interweave approach allow access of spectrum to SUs only when PUs are not in operation.

In order to sort out aforementioned issues, lots of researches are going on in this area such as joint or hybrid approach to provide efficient resource utilization with power and subcarrier allocation.

5. PROBLEM FORMULATION FOR OPTIMAL POWER ALLOCATION

5.1 SYSTEM MODEL

As shown in Fig.3, we consider a hybrid scenario for primary and SUs under condition of downlink transmission where cognitive user is transmitting information to other CR users using dynamic allocation of entire spectrum bandwidth B while keeping interference below threshold level. As we use OFDM based CR system, where entire spectrum divides in to S numbers of subcarriers band. Spectral distance between two adjacent subcarrier given by;

$$\Delta B = \frac{B}{S}$$

Various other parameters that are going to be used in our system model are as follow:

Let C is number of cognitive users and number of overlay and underlay subcarriers are O and U respectively. Total number of subcarriers are $S=O+U$.

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

$H^{S,S}(i)$: Complex channel gain corresponding to i^{th} subcarrier between SU Tx and SU Rx.

$H^{S,P}(i)$: Complex cross channel gain corresponding to i^{th} subcarrier between SU Tx and PU Rx.

P_i: Transmit power on i^{th} subcarrier of SU.

$I_i^{s,P}$: Interference factor which is interference caused by i^{th} subcarrier of SU Tx to PU Tx due to nature of pulse as sinc wave.

$I_i^{p,s}$: Interference power of PU on i^{th} subcarrier of SU user. (PU Tx to SU Rx).

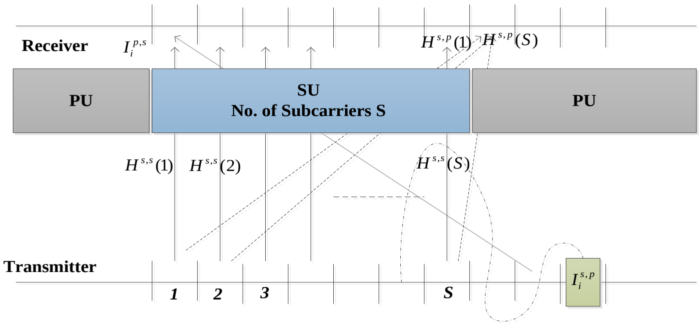

Fig.3. System Model for Interweave Scenario in OFDM based Cognitive Radio

5.2 EXPRESSION OF OPTIMAL POWER CONTROL FOR SU IN INTERWEAVE SCENARIO [16] [17]

Due to sinc nature of subcarrier waveform, interference introduced by CR to PU

$$I_i^{s,p}\left(d_i, P_i\right) = P_i T_S \int_{d_{o,u}-\frac{\Delta B}{2}}^{d_{o,u}+\frac{\Delta B}{2}} \left(\frac{\sin \pi f T_s}{\pi f T_s}\right)^2 df \tag{1}$$

where: $d_{o,u}$ Spectral distance between o^{th} subcarrier of SU i.e. overlay and u^{th} subcarrier of PU i.e. underlay. Operating frequency and Symbol time duration are given as T_S and f respectively.

Spectral distance factor given by

$$f_i\left(d_{o,u}\right) = T_S \int_{d_{o,u}-\frac{\Delta B}{2}}^{d_{o,u}+\frac{\Delta B}{2}} \left(\frac{\sin \pi f T_s}{\pi f T_s}\right)^2 df \tag{2}$$

Here optimization objective for SU can be defined as maximization of sum rate which can be given as [18] [19]:

$$= \max \sum_{i=1}^{S} \log_2 \left(1 + \frac{P_i \left|H^{S,S}(i)\right|^2}{\sigma^2 + I_i^{p,s}}\right) \tag{3}$$

Subject to constraint:

$$\sum_{i=1}^{S} P_i \left|H^{s,p}(i)\right|^2 f_i\left(d_{o,u}\right) \le I_{th} \tag{4}$$

As this condition having linear constraint and linear constraint is always convex so here also it will be problems of convex constraint which can be solve using Lagrange formula as:

(Optimization Objective) + (Lagrange Constant) × (Constraint)

Using Lagrange formulation, solution for objective function under given constraint can be written as:

$$\begin{aligned} &= \max \sum_{i=1}^{S} \log_2 \left(1 + \frac{P_i \left|H^{S,S}(i)\right|^2}{\sigma^2 + I_i^{p,s}}\right) \\ &+ \alpha \left(I_{th} - \sum_{i=1}^{S} P_i \left|H^{s,p}(i)\right|^2 f_i\left(d_{o,u}\right)\right) \end{aligned} \tag{5}$$

where α is the Lagrange constant.

Differentiate equation (5) w.r.t. P_i and equate with zero.

$$\left[\frac{\left[\frac{\left|H^{S,S}(i)\right|^2}{\sigma^2+I_i^{p,s}}\right]}{\left[1+\frac{P_i\left|H^{S,S}(i)\right|^2}{\sigma^2+I_i^{p,s}}\right]}\right]+\alpha\left(\frac{-\left|H^{s,p}(i)\right|^2}{f_i(d_{o,u})}\right)=0 \qquad (6)$$

Optimal power expression for SU can be given as [20] [21]:

$$P_i=\left[\frac{1}{\alpha\left(\left|H^{s,p}(i)\right|^2 f_i(d_{o,u})\right)}-\frac{\sigma^2+I_i^{p,s}}{\left|H^{s,s}(i)\right|^2}\right] \qquad (7)$$

To find Lagrange constant α, constraint given in Eq.(4) will be used.

$$\frac{1}{\alpha}=I_{th}+\sum_{i=1}^{S}\left(1+\frac{(\sigma^2+I_i^{p,s})\left|H^{s,p}(i)\right|^2 f_i(d_{o,u})}{\left|H^{s,s}(i)\right|^2}\right) \qquad (8)$$

5.3 EXPRESSION FOR OPTIMAL POWER OF SU IN JOINT OVERLAY AND UNDERLAY SCENARIO:

Here optimization objective can be defined as maximization of sum rate which can be given as:

$$C=\Delta B\sum_{j=1}^{C}\sum_{i=1}^{S}x_{j,i}\log_2\left(1+\frac{P_{j,i}\left|H_j^{S,S}(i)\right|^2}{\sigma^2+I_{j,i}^{p,s}}\right) \qquad (9)$$

where $x_{j,i}$ is assigned as unity once subcarrier allocation done for j^{th} SU on i^{th} subcarrier otherwise it is zero. After subcarrier allocation above equation can be rewritten as:

$$=\max\sum_{j=1}^{C}\sum_{i\in U}\log_2\left(1+\frac{P_{j,i}\left|H_j^{S,S}(i)\right|^2}{\sigma^2+j_{j,i}}\right) \qquad (10)$$

Let $H_j^{s,P}(i)$ to be Rayleigh distributed with known parameter η. Variable a is value of probability that interference occurs at PU i.e. underlay subcarrier remain below defined value of I_{th}.

Subject to constraint:

$$=\max\sum_{j=1}^{C}\sum_{i\in U}P_{j,i}\,f_i(d_{o,u})\le\frac{I_{th}}{2\eta^2(-\ln(1-a))} \qquad (11)$$

and

$$P_{j,i}\ge 0 \; for \; j=1,2,\ldots,C$$

$$\sum_{j=1}^{C}\sum_{i\in U}P_{j,i}\le P_T \qquad (12)$$

As these constraints are linear and linear constraint is always convex so here also it will be a problem of convex constraint. Similarly as derived in Eq.(5) and Eq.(6), by using Lagrange formulation, solution for objective function as given in Eq.(10) under given constraint in Eq.(11) and Eq.(12) can be obtained when differentiate equation of Lagrange formulation w.r.t. P_i and equate with zero.

Optimal power expression can be derived as [22] [23]:

$$P_{j,i}=\left[\frac{1}{\beta f(d_{k,l})+\gamma}-\frac{\sigma^2+I_{j,i}^{p,s}}{\left|H_j^{S,S}(i)\right|^2}\right] \qquad (13)$$

Here β and γ are Lagrange constants which can be estimated using given constraints in equation (11) and (12).

6. SIMULATION RESULT

Here we assumed number of cognitive users, overlay subcarriers and underlay subcarriers as C=2, U=4 and O=4 respectively. AWGN power per subcarrier σ^2 = 1.3×10^{-15} W and Interference threshold taken as 500σ^2W. Power allocation in OFDM based CR given by ladder type profile with following parameters as number of sub channel is 32, total transmit power -20dBm, total available bandwidth is 1 MHz and noise density -80dBm. 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.

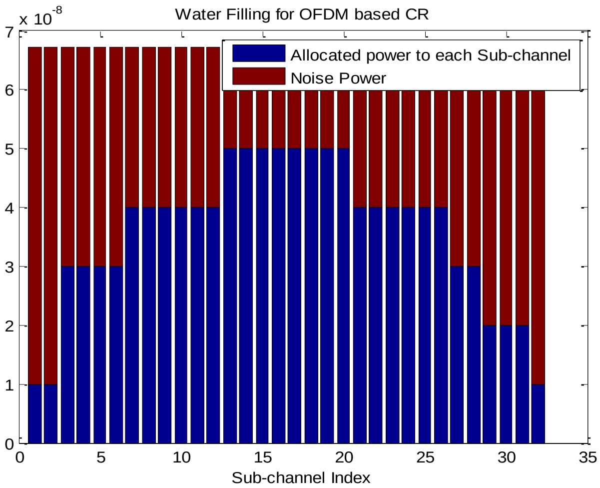

Fig.4. Waterfilling algorithm for OFDM based CR

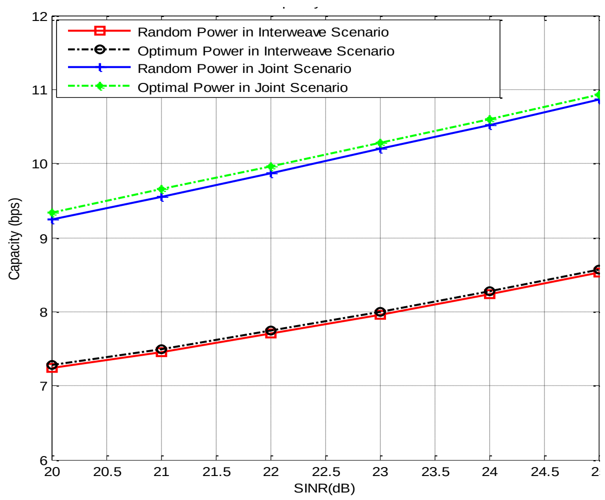

Fig.5. Transmission capacity of SU vs. SINR for different scenario

As in OFDM based CR, system capacity enhanced, due to dynamic frequency allocation, here SU is transmitting optimal power as derived in section 4, while keeping interference constraint imposed by PU below threshold value. From simulation result in Fig.5, it has been observed that optimal power allocation of SU provides better capacity when compare with random power allocation in both the cases as interweave scenario and joint scenario. Due to efficient utilization of resources in unused spectrum and under-utilization cases, joint scenario shows improved capacity than interweave scenario.

7. CONCLUSION AND FUTURE SCOPE

OFDM based CR provides dynamic and flexible spectrum sharing using DSA make this technology versatile and an emerging. This paper explained OFDM based CR system and Problem formulation on optimal transmit power control of SU in OFDM based CR under various spectrum sharing approach as interweave and joint underlay and overlay approach have been derived. In both the cases interweave and joint scenario, transmission capacity of SU have been improved significantly, when SU transmit optimal power. It has been observed that joint scenario shows better capacity compare to interweave approach.

In various literatures, it has been seen that neither underlay nor overlay approach is able to mitigate both problem simultaneously related to unused spectrum and underutilized spectrum to make efficient utilization of available resource. Therefore joint and hybrid scenario may be proposed in upcoming paper for spectrum sharing and optimal power allocation for MIMO-OFDM based CRN also can be illustrated using various techniques.

REFERENCES

[1] M. Milosavljevic, S. Sofianos, P. Kourtessis and M. John, "Self-Organized Cooperative 5G RANs with Intelligent Optical Backhauls for Mobile Cloud Computing", *Proceedings of IEEE Workshop on Optical-Wireless Integrated Technology for Systems and Networks*, pp. 900-904, 2013.

[2] Spectrum Policy Task Force, "Report of the Spectrum Efficiency Working Group", Available at: https://transition.fcc.gov/sptf/files/SEWGFinalReport_1.pdf, Accessed at 2002.

[3] R.W. Broderson, A. Wolisz, D. Cabric, S.M. Mishra and D. Willkomm, "A Cognitive Radio Approach for Usage of Virtual Unlicensed Spectrum", *Proceedings of 14th International Workshop and Conference Summit on Wireless Communications*, pp. 1-9, 2004.

[4] S. Haykin, "Cognitive Radio: Brain-Empowered Wireless Communications", *IEEE Journal on Selected Areas in Communications*, Vol. 23, No. 2, pp. 201-220, Feb. 2005.

[5] E. Hossain and V.K. Bhargava, "*Cognitive Wireless Communication Networks*", Springer Publisher, 2007.

[6] J. Mitola and G.Q. Maguire, "Cognitive Radios: Making Software Radios More Personal", *IEEE Transactions on Communications*, Vol. 6, No. 4, pp. 13-18, 1999.

[7] A.M. Wyglinski, "Effects of Bit Allocation on Non-Contiguous Multicarrier-Based Cognitive Radio Transceivers", *Proceedings of International Conference on Vehicular Technology*, pp. 1-5, 2006.

[8] J.A.C. Bingham, "Multicarrier Modulation for Data Transmission: An Idea Whose Time has Come", *IEEE Communications Magazine*, Vol. 28, No. 5, pp. 5-14, 1990.

[9] D. Cabric and R.W. Brodersen, "Physical Layer Design Issues Unique to Cognitive Radio Systems", *Proceedings of IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 759-763, 2005.

[10] A. Goldsmith, S.A. Jafar, I. Maric and S. Srinivasa, "Breaking Spectrum Gridlock with Cognitive Radios: An Information Theoretic Perspective", *Proceedings of the IEEE*, Vol. 97, No. 5, pp. 894-914, 2009.

[11] T. Peng, W. Wang, Q. Lu and W. Wang, "Subcarrier Allocation based on Water-Filling Level in OFDMA-Based Cognitive Radio Networks", *Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 196-199, 2007.

[12] Z. Wu and B. Natarajan, "Interference Tolerant Agile Cognitive Radio: Maximize Channel Capacity of Cognitive Radio", *Proceedings of International Conference on Consumer Communications and Networking*, pp. 1027-1031, 2007.

[13] D.I. Kim, L.B. Le and E. Hossain, "Joint Rate and Power Allocation for Cognitive Radios in Dynamic Spectrum Access Environment", *IEEE Transactions on Wireless Communications*, Vol. 7, No. 12, pp. 5517-5527, 2008.

[14] C.Y. Wong, R.S. Cheng, K.B. Letaief and R.D. Murch, "Multiuser OFDM with Adaptive Subcarrier, Bit, Power, and Power Allocation", *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 10, pp. 1747-1758, 1999.

[15] D. Ngo, C. Tellumbra and H.H. Nguyen, "Resource Allocation for OFDM-Based Cognitive Radio Multicast Networks", *Proceedings of IEEE International Conference on Wireless Communications and Networking*, pp. 1-6, 2009.

[16] Chaeriah Bin Ali Wael, N. Armi, M. Tajul Miftahushudur, D. Muliawarda and G. Sugandi, "Power Allocation in OFDM-Based Cognitive Radio Networks for Fading Channel", *Proceedings of International Conference on Radar, Antenna, Microwave, Electronics and Telecommunications*, pp. 1-14, 2017.

[17] Ajmery Sultana, L. Zhao and X. Fernando, "Power Allocation using Geometric Water Filling for OFMD-Based Cognitive Radio Networks", *Proceedings of IEEE International Conference on Vehicular Technology*, pp. 1-6, 2016.

[18] Ravi Kumar Jangir, "Power Allocation Schemes for OFDM Based Cognitive Radio Networks", *Proceedings of IEEE International Conference on Recent Advances in Engineering and Computational Sciences*, pp. 112-118, 2015.

[19] Manoranjan Rai Bharti and Debashis Ghosh, "Spectrum Efficient Power Allocation Schemes for OFDM Cognitive Radio with Statistical Interference Constraints", *Physical Communication*, Vol. 24, pp. 169-181, 2017.

[20] G. Bansal, M.D.J. Hossain and V.K. Bhargava, "Optimal and Suboptimal Power Allocation Schemes for OFDM-Based Cognitive Radio Systems", *IEEE Transactions on*

Wireless Communications, Vol. 7, No. 11, pp. 4710-4718, 2008.

[21] G. Bansal, M.D.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 Transactions on Vehicular Technology*, Vol. 62, No. 3, pp. 1111-1122, 2013.

[22] T.C.H. Alen, A.S. Madhukumar and F. Chin, "Capacity Enhancement of a Multi-User OFDM System using Dynamic Frequency Allocation", *IEEE Transactions on Broadcasting*, Vol. 49, No. 4, pp. 344-353, 2003.

[23] Manoranjan Rai Bharti and Debashis Ghosh, "Active Interference Cancellation Based Optimal Power Loading for OFDM Cognitive Radio", *Proceedings of IEEE International Conference on Communications*, pp. 1-7, 2017.