

Power Allocation in Cognitive Radio Networks using Genetic Algorithm



Keshav Mishra, Aditya Trivedi, Rekha Gupta,

Abstract: Cognitive radio is one of the Frontline areas in wireless communication. With the evolution of 5th generation wireless communication techniques, the expected use of cognitive-communication will be enhanced. The joint model consisting of the Overlay and Underlay spectrum mechanism has been considered for transmission rate optimization using the genetic algorithm and the performance improvement has been recorded over the suboptimum scheme using the JOUSAM model for the cognitive radio network. For a given power budget and interference limit, the transmission rate is optimized with respect to power and bandwidth.

Keywords: Cognitive radio, JOUSAM, GA, Wireless communication, etc.

I. INTRODUCTION

Lack of spectrum availability and its increasing requirement is a challenging area of a wireless system. In this direction, cognitive radio becomes one of the solutions for this problem, which utilizes the unused frequency spectrum of the primary users. This spectrum sharing technique allows the multiuser to communicate their data on the same frequency spectrum. Another situation is the underutilization of the spectrum band. Hence two types of spectrum sharing systems may be suggested for secondary user data transmission. First is underlay and the other is overlay spectrum access [1-6]. Figure 1 shows the mechanism of both schemes. For efficient utilization of spectrum, CR systems are required to use the unused and underutilized spectrum. Hence, a scheme is proposed for power allocation in a joint overlay and underlay spectrum access mechanism (JOUSAM) for [8]. Figure 2 shows the JOUSAM scheme. The purpose of the proposed scheme is transmission rate optimization and it is done concerning power budget and bandwidth. By doing so, the enhancement of transmission rate of CR users is achieved for available power and interference limit. Many researchers had published their work in this field. Some of the related work is described below. K.R. Shanthy M. E. Et.al, in this paper authors, has considered joint underlay and overlay resource allocation for the cognitive radio system. Results show that an improvement in the transmission rate is achieved in comparison with OSAM or the USAM.

A suboptimal technique is also designed to provide fairness among cognitive users, although compromising with transmission rate [10]

Peng Wang, et. Al, In this paper, to allocate power in the Cognitive Radio system, the traditional water filling method applied in general OFDM is modified due to the per sub-channel power constraints in such systems. They have proposed an iterative partitioned water-filling algorithm for power allocation in cognitive radio systems using OFDM. The Primary Users (PUs) suffer interferences caused by not only the Secondary Users (SUs) transmission in the corresponding sub-channel but also the side-lobes of other sub-channels, which was not considered in this paper [11].

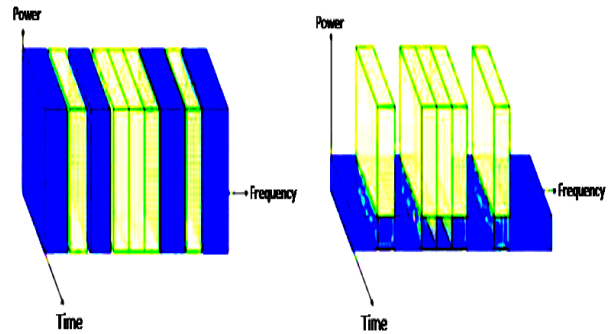


Figure1: Overlay and underlay scheme for spectrum access for cognitive radio[7]

Chin-Hsu Chen, in this paper, the authors have proposed the power allocation scheme considering the primary user activity technique. The proposed power allocation problem becomes maximizing the sum capacity, to do so, water filling is used and performance approaches that of the optimal one. [12].

In [13], imperfect sensing has been identified as one of the reasons for the interference. Also, authors have considered interference due to missed detection while designing power allocation schemes to maximize transmission capacity, but interference because of primary users (PUs) and secondary (SUs) co-existence is not considered

A suboptimal resource allocation scheme is proposed by G. Bansal et. Al. [9]. An improvement in terms of total achievable transmission rates compared to USAM or an OSAM has been observed. According to the suboptimal scheme in this paper, each underlay subcarriers are supplied with constant power while the overlay subcarriers are supplied following a ladder profile, as discussed in [6]

Motivated by the above works on resource allocation, particularly in [9], in this paper, we have proposed a new power allocation scheme for the CR system with a JOUSAM using a genetic algorithm. Our contribution can be summarized as follows: with GA it is easy to handle the multivariable and multiobjective problem with nonlinear constraints.

Manuscript published on 30 September 2019.

*Correspondence Author(s)

Keshav Mishra*, Department of Electronics and Communication, MITS, Gwalior, India, Email: kjairam09@gmail.com

Dr. Aditya Trivedi, Information and Communication Technology (ICT) Department, ABV Indian Institute of Information Technology and Management, Gwalior, India.

Dr.Rekha Gupta, Department of Electronics and Communication, MITS, Gwalior, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

Therefore, we have proposed a GA based approach that can improve the performance as compared to the suboptimal resource allocation scheme. Results in this paper show that, for specified interference value, an improvement in the transmission rate is recorded by this method. The scheme is based on the optimization of a cost function. This cost function essentially enhanced the transmission rate and reduce the interference

The paper is organized as follows. The mathematical system model is described and the objective function is formulated in Section 2. The proposed GA Based approach is given in Section 3. results using a GA based approach are discussed in Section 4. conclusions are presented in Section5.

II. SYSTEM MODEL

A. Mathematical modeling

PU and CR users forming a coexistence scenario are depicted in Figure.2.

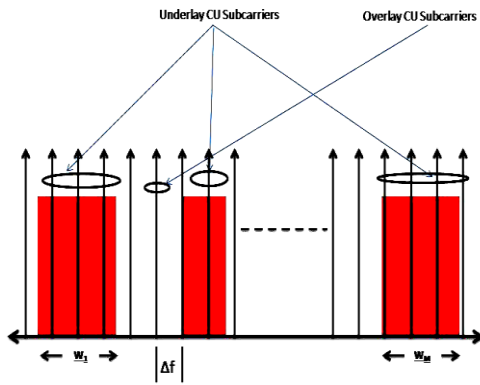


Figure2: Scheme of joint underlay and overlay spectrum access mechanism for cognitive radio [9]

Let consider, for a given geometrical area, total W bandwidth is allotted to primary users. W bandwidth is divided into M parts for different primary user groups.

$$W = \sum_{m=1}^M W_m \quad (1)$$

Where W_m is the bandwidth of the m th primary user group. Consider K CR users are also using the bandwidth W. For Z subcarriers of CR users, the spectral distance between subcarriers can be given as

$$\Delta f = \frac{W}{Z} \quad (2)$$

both overlay and underlay subcarriers are contained in Z subcarriers (i.e. $Z=N+L$). The power spectral density $\phi_k(f)$ is given as [5]

$$\phi_k(f) = P_k T_s \text{Sinc}^2(f T_s) \quad (3)$$

Where T_s and p_k are symbol duration and the power allocated in the k th subcarrier respectively.

Let h_l^{SP} is fading coefficient of the channel between CR transmitter and u th PU subcarrier.

The interference created by CR subcarrier to l th primary user group can be given as [5][6].

$$I_l^{SP} = |h_l^{SP}|^2 \sum_{u=1}^K \sum_{k=1}^Z \rho_{u,k} p_{u,k} F(d_{k,l}) \quad (4)$$

Where $\rho_{u,k}$ denotes the status (0 or 1) if the k th subcarrier is allocated to the u th CR user or not. $p_{u,k}$ is the transmitted power by the u th CR user in the k th subcarrier. spectral

distance factor $F(d_{k,l})$ is defined as [9].

$$F(d_{k,l}) = T_s \int_{d_{k,l}-\frac{\Delta f}{2}}^{d_{k,l}+\frac{\Delta f}{2}} \text{Sinc}^2(f T_s) df \quad (5)$$

Let $h_{u,k}^{SS}$ is fading channel coefficient between u th CR user in k th subcarrier and CR transmitter of all CR hence, the transmission rate for secondary users is given using the well-known Shannon capacity formula, the theoretical total transmission rate of all CR users can be written as

$$C = \Delta f \sum_{u=1}^K \sum_{k=1}^Z \rho_{u,k} \log \left(1 + \frac{|h_{u,k}^{SS}|^2 p_{u,k}}{\sigma^2 + J_{k,u}} \right) F(d_{k,l}) \quad (6)$$

σ^2 denotes the additive white Gaussian noise (AWGN) variance, $J_{k,u}$ denotes the interference introduced to the k th subcarrier of the u th CR user due to the transmission of all PUs. Interference is $J_{k,u}$ treated as Gaussian in the capacity formula

B. Problem domain

To enhance the total transmission rate C with minimizing the interference for all primary users different spectrum access techniques are applied to CR systems while doing so the Probability (Pr) for interference should remain below a certain value a to the l th underlay subcarrier. Therefore, the objective function for a given power budget (PT) is given as

$$\max_{p_{u,k}, \rho_{u,k}} C = \Delta f \sum_{u=1}^K \sum_{k=1}^Z \rho_{u,k} \log_2 \left(1 + \frac{|h_{u,k}^{SS}|^2 p_{u,k}}{\sigma^2 + J_{u,k}} \right) \quad (7)$$

$$\text{Conditions } P_r (i_l^{SP} < I_{th}^l) > a. \quad (8)$$

$$\sum_{u=1}^K \sum_{k=1}^Z \rho_{u,k} p_{u,k} \leq P_T \quad (9)$$

$$\sum_{u=1}^K \rho_{u,k} = 1 \ \& \ \rho_{u,k} = \{0,1\} \quad (10)$$

for all u and k

C. Subcarrier allocation and Objective function

To achieve the goal defined by equation7, subcarrier allocation to a CR user should be done satisfying the following conditions

$$\rho_{u,k} = \begin{cases} 1 & \text{when } u = u^* \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

$$\text{Where, } u^* = \arg \max_u \frac{|h_{u,k}^{SS}|^2}{\sigma^2 + J_{u,k}}, \text{ for } k = 1, 2, \dots, Z \quad (12)$$

After subcarrier allocation according to (12), the equation (7) can be written as

$$\max_{p_{u,k}} \sum_{u=1}^K \sum_{k \in \Omega_u} \log_2 \left(1 + \frac{|h_{u,k}^{SS}|^2 p_{u,k}}{\sigma^2 + J_{u,k}} \right) \quad (13)$$

The channel type is Rayleigh channel and if Rayleigh parameter is β_l . Then equation(8) can be written as

$$\sum_{u=1}^K \sum_{k \in \Omega_u} p_{u,k} f(d_{k,l}) \leq \frac{I_{th}^{(l)}}{2\lambda_l^2 (-\ln(1-a))} \quad l \in S_U \quad (14)$$

$$\sum_{u=1}^K \sum_{k \in \Omega_u} p_{u,k} \leq P_T \quad (15)$$

III. PROPOSED GA BASED APPROACH

GA, is well suited for multi-variant, multi-objective and non-mathematical optimization in CR networks. GA can search for multiple sets of solutions over a huge search space and it can enforce constraints of the problem [14].

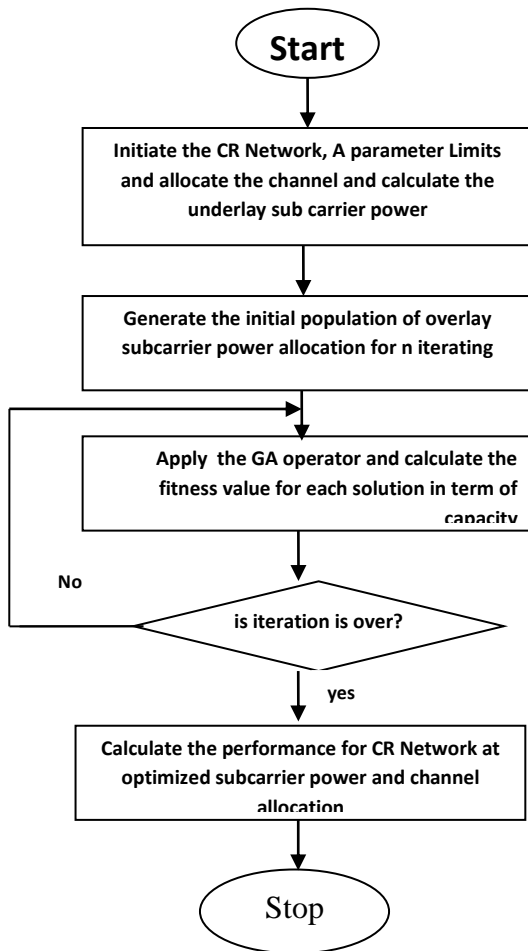


Figure 3: Flowchart of the GA based optimization for power allocation of overlay subcarrier.

GA is an excellent optimization tool due to fast convergence, ease of implementation, and optimization of discrete and continuous radio parameters, render for making resource management decisions in CR networks [15] [16]. The problem 13 is optimized by a genetic algorithm for constraints in equations 14 and 15. The flow chart of optimization is shown in figure3. In this paper, optimization has been performed in terms of the power distribution of overlay subcarrier using GA. The underlay subcarriers power is kept fixed and overlay subcarrier power is calculated as

$$P_{oi} = I_i * x * P_u \quad (16)$$

where

P_{oi} is the power of i th overlay subcarrier, x is the constant factor which will be determined by simulation and P_u is underlay subcarriers power and I_i is given as

$$I_i = \frac{\Delta_i}{\Delta f} \quad (17)$$

Where Δf is the spectral distance, Δ_i is the spectral distance between the i th overlay subcarrier and the closest PU band

In [9] the x is considered as constant for all overlay subcarriers irrespective of the channel conditions. For better power allocation, it is proposed to use the GA to optimize the overlay subcarriers' power by modifying the value of x for each overlay subcarrier. Therefore, equation (16) is modified as

$$P_{oi} = I_i * x_i * P_u \quad (18)$$

The optimization function may be defined as

$$\max_{x_i} = \Delta f \sum_{u=1}^K \sum_{k=1}^Z \rho_{u,k} \log_2 \left(1 + \frac{|h_{u,k}^{SS}|^2 \rho_{u,k}}{\sigma^2 + j_{u,k}} \right) \quad (19)$$

Each x_i is optimized with the constraint[9]

$$(L * P_u + \sum_{i=1}^N I_i * x_i * P_u) \leq P_T \quad (20)$$

The allocation of channel and underlay subcarrier power is calculated using the mathematical model and overlay subcarrier power is obtained by using GA based optimization. The results of the above method are described in the next section of this paper.

IV. RESULTS

The Rayleigh wireless channel is used for simulation. The parameters of the simulations are shown in Table1 and the channel conditions (magnitude and Raleigh distribution) are shown in figure 4.

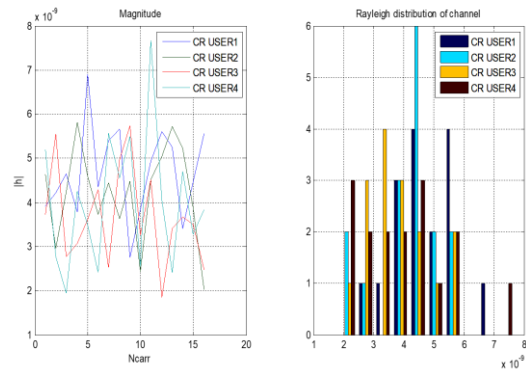


Figure 4: Rayleigh channel magnitude and distribution for CR users

Table.1 Parameters used for channel conditions

S. No.	Parameters	Specificatio n
1	No .of primary Users	10
2	No .of cognitive radio user	4
3	No. of CR subcarrier	16
4	No. of underlay subcarrier	8
5	No. of overlay subcarrier	8
6	Bandwidth	Up to 5 MHz
7	Signal to Noise ratio	-10 dBm
8	Power budget	1to 9 mW
9	Interference threshold	500

The transmission rate optimization is the main key of all the simulations. The rate depends on the bandwidth and SNR for data transmission over the network. The simulation has been performed in two phases

A. Transmission rate optimization for different power budget

Transmission rate optimization for different power budget with optimum power distribution is performed. The optimum power distribution to overlay the subcarrier is used to maximize the transmission rate.

Power Allocation in Cognitive Radio Networks using Genetic Algorithm

The transmission rate for the proposed method using the GA algorithm is shown in Figure 5. The Ladder based approach for overlay subcarrier power is also shown in red color. The numerical results show that the GA based approach has produced improved results. The maximum transmission rate achieved is 13.3 Mbps using GA based method as compared to 12.7 Mbps for ladder based power allocation method.

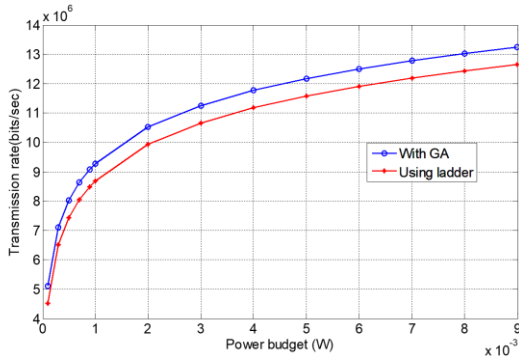


Figure 5: Transmission rate for proposed method using GA algorithm

An enhancement of 5% has been observed with the proposed method. Almost 12 iterations or generation is required to converge the optimization.

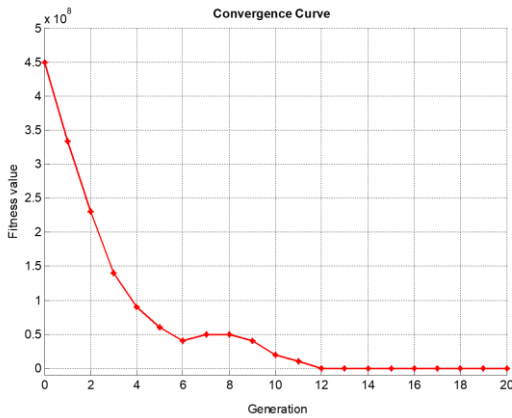


Figure 6: Convergence curve of GA for transmission rate optimization

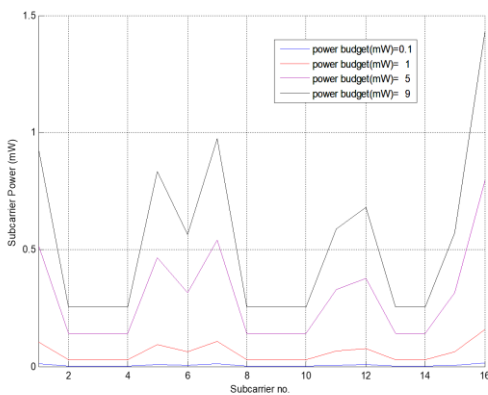


Figure 7: Optimum overlay and underlay subcarrier power.

Table.2 The GA parameters used for simulation

S. No.	Parameters	Specification
1	No. of variables	8(No. of overlay subcarrier)
2	No. of population size	25
3	No. of Generation	20,50,100
4	Lower boundary of variable	1
5	Upper boundary of variable	4

The corresponding convergence curve of the optimization is shown in figure 6. The optimum power distributions to the overlay subcarriers for the different power budgets are shown in figure 7. In the graph, constant points show the underlay subcarriers and other points showing overlay subcarrier. It is clear from the graph, the overlay subcarrier power distributions are modified with an increase in the power budget

B . Transmission rate Optimization with different Bandwidth:

The other important aspect is to improve the rate at different bandwidth. The same parameters of the network have been used for simulation except for the power budget. The fixed power budget is used in the simulation. The parameters of the simulation for this purpose are shown in table3.

Table.3. Parameters of the simulation

S. No.	Parameters	Specification
1	No. of Primary Users	10
2	No. of cognitive radio user	4
3	No. of CR subcarrier	16
4	No. of underlay subcarrier	8
5	No. of overlay subcarrier	8
6	Bandwidth	1 to 5 MHz
7	Signal to Noise ratio	-10 dBm
8	Power budget	1 mW
9	Interference threshold	500

The transmission rate is linearly varied with the bandwidth. The proper distribution of the power to subcarriers improves the increasing trend of transmission rate w.r.t. bandwidth. The genetic algorithm-based optimization is used to optimize power distribution to subcarriers. The Cost function used for the optimization is given as

$$\text{maximum } F_{out} = \sum_{k=0}^n R(k)$$

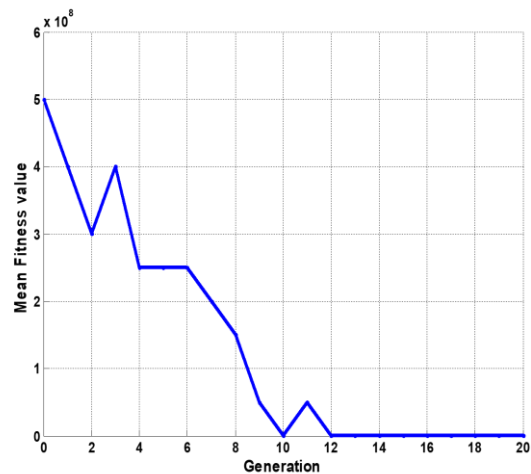


Figure8: Optimization curve for transmission rate optimization for different signal power

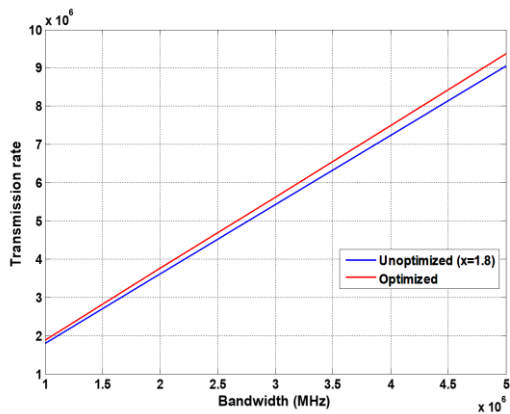


Figure9 : Improvement in the transmission rate with bandwidth using genetic algorithm

Where the power budget cases used in the optimization is n . and $R(k)$ is the rate at condition k . The convergence curve for genetic algorithm-based optimization is shown in figure8. The improvement of the transmission rate is shown in figure9. At a bandwidth of 5MHz, improvement of almost 0.3 Mbps has been recorded in the transmission rate. About 3-4 % enhancement was observed with the optimization concerning bandwidth

V. CONCLUSION

The power allocation to overlay subcarriers using GA is done and the performance is compared to a ladder based approach. Optimization is performed concerning different power budget and bandwidth. Improvement in the transmission rate concerning bandwidth using a genetic algorithm is significant at high power as can be observed from figure9. More complicated problems with several subcarriers and considering underlay subcarrier power can be solved with a similar approach. The other evolutionary approach can also be tried to improve the speed of optimization with the much-complicated problem

REFERENCES

1. J. Mitola, III and G. Q. Maguire, Jr., "Cognitive radios: Making software radios more personal," IEEE Pers. Commun., vol. 6, no. 4, pp. 13–18, Aug. 1999.
2. D. Cabric and R. W. Brodersen, "Physical layer design issues unique to cognitive radio systems," in Proc. IEEE Int. Symp. PIMRC, Sep. 2005, pp. 759–763.
3. S. Haykin, "Cognitive radio: Brain-empowered wireless communications," IEEE J. Sel. Areas Commun., vol. 23, no. 2, pp. 201–220, Feb. 2005.
4. E. Hossain and V. K. Bhargava, Cognitive Wireless Communication Networks. New York: Springer-Verlag, 2007.
5. 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.
6. 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.
7. I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/ dynamic spectrum access/cognitive radio wireless networks: A survey," Comput. Netw., vol. 50, pp. 2127–2159, May 2006.
8. G. Bansal, O. Duval, and F. Gagnon, "Joint overlay and underlay power allocation scheme for OFDM-based cognitive radio systems," in Proc. IEEE VTC, Taipei, Taiwan, May 2010, pp. 1–5.
9. Bansal, Gaurav, Md. Jahangir Hossain, Vijay K. Bhargava and Tho Le-Ngoc. "Subcarrier and Power Allocation for OFDMA-Based Cognitive Radio Systems With Joint Overlay and Underlay Spectrum

- Access Mechanism." IEEE Transactions on Vehicular Technology 62 (2013): 1111-1122
10. K. R. Shanthi M. E., M. Suganthi2 and S. Kumaran, "Resource Allocation For OFDMA Based Cognitive Radio System Using Joint Overlay And Underlay Spectrum Access Mechanism", ARPN Journal of Engineering and Applied Sciences, VOL. 10, NO. 8, MAY 2015
11. Peng Wang, Ming Zhao, Limin Xiao, Shidong Zhou, Jing Wang, "Power Allocation in OFDM-based Cognitive Radio Systems", IEEE GLOBECOM 2007
12. Chiuan-Hsu Chen, Chin-Liang Wang, "Power Allocation for OFDM-Based Cognitive Radio Systems under Primary User Activity", IEEE 2010.
13. S. M. Almalfouh G. L. Stuber, "Interference-aware radio resource allocation in OFDMA-based cognitive radio networks," IEEE Trans. Veh. Technol., vol. 60, no. 4, pp. 1699–1713, May 2011.
14. Ludovic Me, "Audit de securite par algorithmes genetique", university of Rennes I, France, 1994.
15. E Adamopoulou, K Demestichas, M Theologou, Enhanced estimation of configuration capabilities in cognitive radio. IEEE Commun. Mag. 46(4), 56–63 (2008)
16. Jamal Elhachmi; Zouhair Guennoun "Cognitive radio spectrum allocation using genetic algorithm" EURASIP Journal on Wireless Communications and Networking 2016:133

AUTHORS PROFILE



Keshav Mishra received the Bachelor's degree in Electronics and Communication Engineering from the Barkatullah University, Bhopal in 1999, ME in 2005 from RGPV, Bhopal in 2005. currently, He is doing his Ph.D. from RGPV, Bhopal. E-mail kjairam09@gmail.com



Dr. Aditya Trivedi is a Professor in the ICT Department of ABV-IIITM, Gwalior, India. He obtained his Ph.D. from IIT Roorkee in the area of Wireless Communication Engineering. His teaching and research interest include Digital communication, CDMA systems, Signal processing, and Networking. He is a fellow of the Institution of Electronics and Telecommunication Engineers (IETE) and a member of Institution of Electrical and Electronics Engineers (IEEE), USA. Email id: atrivedi@iiitm.ac.in



Dr. Rekha Gupta received the Bachelor's degree in Electronics Engineering from the Jiwaji University, Gwalior and the M.E degree in Communication Systems from the IIT, Roorkee. Ph.D. degree in Wireless Mobile Communication from RGPV Bhopal. Currently, she is working as Associate Professor & Head, Dept of Electronics and Communication Engineering, MITS, Gwalior. Her research interests include wireless communication and digital signal processing. E-Mail: rekha652003@mitsgwalior.in