Paper

Optimization of Spectrum Sensing Parameters in Cognitive Radio Using Adaptive Genetic Algorithm

Subhajit Chatterjee[1], Swaham Dutta[2], Partha Pratim Bhattacharya[3], and Jibendu Sekhar Roy[4]

[1] *University of Engineering and Management, Kolkata, West Bengal, India*
[2] *Reliance Jio Infocomm Ltd., Big Data Analysis, Mumbai, Maharashtra, India*
[3] *Mody University of Science and Technology, Lakshmangarh, Sikar, Rajasthan, India*
[4] *School of Electronics Engineering, KIIT University, Bhubaneswar, Odisha, India*

Abstract—Quality of service parameters of cognitive radio, like, bandwidth, throughput and spectral efficiency are optimized using adaptive and demand based genetic algorithm. Simulation results show that the proposed method gives better real life solution to the cognitive radio network than other known approach.

Keywords—adaptive genetic algorithm, bandwidth, cognitive radio, spectrum sensing, throughput.

1. Introduction

Launching of new wireless services has become difficult due to the shortage of available radio spectrum and the technology cognitive radio (CR) is capable for providing an intelligent solution for better spectrum utilization. The occupancy and non-occupancy of the channels can be sensed by CR transceiver and instantly get into the non-occupied channel avoiding preoccupied ones, which minimizes the interference with other users [1].

Spectrum access is the main perception on which CR is based on. The contributors to the CR are mainly the license holders known as the primary users (PU) allow permission for accessing the spectrum to the non-licensed users, i.e. secondary users (SU) as long as interference to PU activity is minimal and limited [2].

Spectrum sensing is the most crucial activity in CR because the SU senses a spectrum to check the presence or absence of a PU signal and dependent upon the QoS parameters or sensing parameters like bandwidth, signal-to-noise ratio (SNR), bit error probability, spectral efficiency, throughput. In this work, sensing parameters, i.e. bandwidth, throughput, and spectral efficiency, are considered and studied. These parameters are optimized on time varying characteristic of spectrum hole under deliberation. Implementation of cognitive radio system lies on two primary steps, spectrum sensing and estimation [3], [4]. SU performs the spectrum sensing which involves sensing to detect the presence of any PU signals to avoid interference and identify accessing opportunity by SU (secondary access). In this work, a genetic algorithm (GA) is used as dependable tool applicable to the radio environment because adaptability is perfect and spectrum efficiency can reach up to 98.50% resulting decrement of sensing time [1], [5], [6].

2. Related Work

Quang *et al.* [6] proposed a throughput-aware routing algorithm for enhancing throughput and decreasing end-to-end delay in industrial cognitive radio sensor networks. The limitation of proposed algorithm is the fact that it requires extra-equipped cluster-heads.

Le *et al.* [7] proposed a bandwidth-aware localized routing algorithm that is suitable for applying to large networks since it is capable of reducing the high computational complexity in such networks.

Kaur *et al.* [4] and Kaur *et al.* [8] proposed algorithms based on the prime principles of GA for optimization of the radio transmission parameters. But, as spectrum hole has the time-varying characteristic in cognitive radio network, the activity of the primary user is one of the concerned factors in time-varying characteristic, i.e. the heterogeneous nature of the spectrum hole is observed by CR user [9].

A number of measurement campaigns relating to spectrum occupancy were conducted worldwide [10], [11]. It is found in one of the campaign that a mean occupancy is as low as 17.4% in the frequency band 30 to 3000 MHz.

3. Demand Based Adaptive Genetic Algorithm

To improve the performance an adaptive GA is proposed where operators and parameters are adaptive to the changing conditions of the spectrum and are executed by controlling the operators and parameters in such a manner that they will alter the values if the population is not producing individuals fit enough. In this work roulette wheel selection is employed with Monte Carlo adaptation by incorporating the time and geographical variance of the radio spectrum.

The simulation of the CR engine is performed by GA to determine the optimal set of sensing parameters. A system is guided by fitness objective towards an optimal state. To achieve this, one multiobjective fitness function is used with weighted sum approach with a purpose each objective can have a representation by a level to symbolize its weight. The algorithm runs with different sets of sensing parameters, denoted as application requested value. The application requested value are time varied for each parameter.

The structure of GA chromosome is composed of three parameters or genes: bandwidth (BW), signal-to-noise ratio (SNR) and bit error probability. Integration of these parameters forms a string (chromosome). Table 1 gives the summarized values of the order of the genes, the ranges of operation and the binary bits required to encode the corresponding integer values.

Table 1
Summarized values of the chromosome structure

Gene set	1	2	3
	Bandwidth [MHz]	Throughput [bits/channel]	Spectral efficiency [bits/s/Hz]
Range	450 to 3000 3000	59795 to 373717	0.000064 to 0.00032
Step size	10	4900	0.0000020
Decimal value range	2550	313922	0.000256
Number of bits required	8	6	7

The three set of parameters specified as genes in chromosome structure need 21 bits for its construction. The composition of this bit string is important because the mutation operation performs at bit level. It is assumed that the parameters be x_1, x_2 and x_3 corresponding to the bandwidth, spectral efficiency and throughput, respectively. Fitness functions for each parameter are generated by [4]:

$$f_i = \left[\frac{w_i |x_i - x_i^d|}{x_i^d} \right], \quad \text{if} \quad |x_i - x_i^d| < |x_i^d|, \tag{1}$$

where x_d^i is the required QoS parameter. w_i is the weight subject to

$$\sum_{i=1}^{3} w_i = 1, \tag{2}$$

where $i = 1, 2, 3$.

Overall fitness function f_{total} is the cumulative sum of individual fitness functions of the parameters given as:

$$f_{total} = \sum_{1}^{3} f_i. \tag{3}$$

Ideally each w_i should be equal 25%, which signifies each gene will have the same weight. But in practical scenario, the weighing factor w can vary according to QoS specifications. The probability of selection for each individual chromosome is given by:

$$p_i = \frac{f_i}{\sum\limits_{i=1}^{n} f_i}, \tag{4}$$

where p_i is the probability of selection of individual chromosome, f_i is the fitness of the individual gene i and n is the number of chromosome in the population.

The throughput can be expressed as [12]

$$Throughput = K\left[\log_2 N_t + \log_2 M\right], \tag{5}$$

where K is the number of primary users, N_t is the Line of Sight (LOS) of transmitting antennas and M is the cardinality of the modulation scheme (in power of 2).

Table 2 shows the working functions of the parameters.

Table 2
Functions of the parameters

Parameters	Equation (function)	Remarks	Constant values
Throughput	Throughput given by Eq. 5	K = number of primary users; N_t = LOS of transmitting antennas; M = cardinality of the modulation scheme	8 users per 200 kHz
Spectral efficiency (SE)	$SE = \frac{mR}{B}$	m = modulation index; R = symbol rate; B = frequency	$m = 0.7$

4. Derivation of TFM and GFM with Chromosome

First step is the creation of initial population and each element of the initial population matrix is represented in binary form. In order to encode the real values of each parameter, corresponding decimal values are used to map them to each binary set of numbers. These decimal values are the reference values on which the total fitness measure (TFM) and gene fitness measure (GFM) are calculated. Apart from this, application requested gene value (taken as user input), gene weight (derived with respect to the gene configuration which is taken as user input) and fitness point of genes (taken as user input) are three prime aspects on which the above parameters are also dependent.

In this work each gene is assigned with decimal value. These values are derived from number of bits assigned to the individual gene and the step size. The individual genes are frequency (bandwidth) marked as Gene 1, throughput (Gene 2) and spectral efficiency (Gene 3). Each gene has an operating range divided into few decimal values and theirs assigned value is dependent on the step size of individual gene. To derive TFM and GFM with chromosome, the decimal values of genes, configuration of gene, and total number of bits in a chromosome are designed. Gene weight is calculated and the demand and need based adaptability of the GA is taken into consideration, i.e. the application requested value of each gene. The application requested value of bandwidth can be of any value, which corresponds to a frequency and this frequency has corresponding application requested values of other genes in the chromosome structure, i.e. SNR, spectral efficiency, and throughput. This application requested values represent the respective values of the mentioned genes in the chromosome.

The TFM can be expressed as:

$$\text{TFM} = 100 - \sum(\text{gene fitness measure of all genes}), \quad (6)$$

$$\text{TFM} = 100 - \sum(\text{GFM\_G1} + \text{GFM\_G2} + \text{GFM\_G3}), \quad (7)$$

where GFM_G1, GFM_G2, and GFM_G3 are the individual gene fitness measures. In this way, the TFM and GFM of a chromosome can be derived (Table 3).

Table 3
Derivation of the TFM and GFM of a chromosome

Input parameters	Value		
Initial population size	100		
Maximum number of generations to be iterated	100		
Crossover rate	80%		
Mutation rate	2%		
Number of bits assigned to each of the genes of the chromosome	8	6	7
Application requested gene values	226	121	10
Fitness points of gene	110	50	6

The gene fitness measure is inversely proportional to the total fitness measure of the chromosome.

5. Simulation

The simulation was made for three application requested values covering almost the entire range. The result is shown for three sets where the plot of total fitness measure, gene fitness measure, variation of each parameters, unoptimized and optimized regions of each parameters are shown.

Case 1 is based on application requested decimal values: bandwidth = 16, throughput = 4, spectral efficiency = 4, initial population = 100, and maximum generations = 100. The Figs. 1 and 2 show TFM and GFM of the adaptive GA.

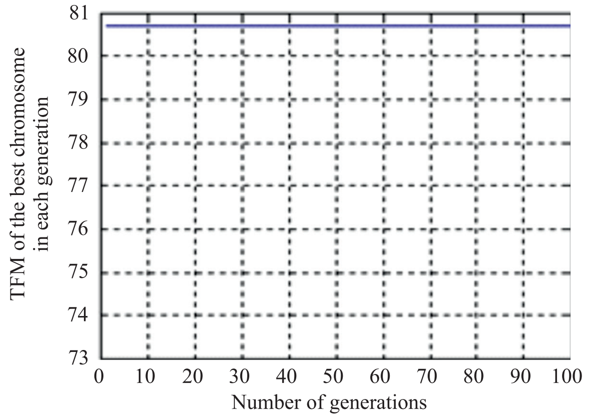

Fig. 1. Variation of TFM of the best chromosome with number of generation.

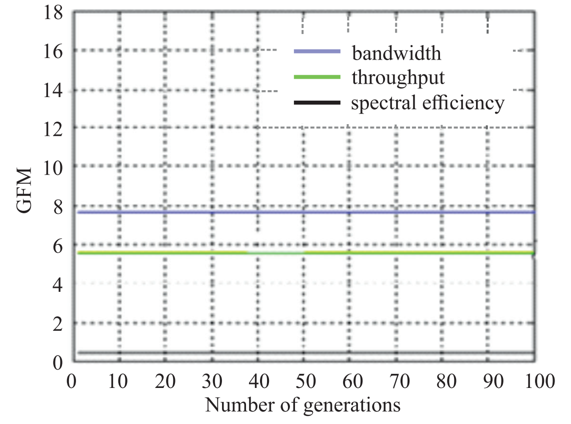

Fig. 2. Variation of GFM of Gene 1, Gene 2, and Gene 3 with number of generations. (See color pictures online at www.nit.eu/publications/journal-jtit)

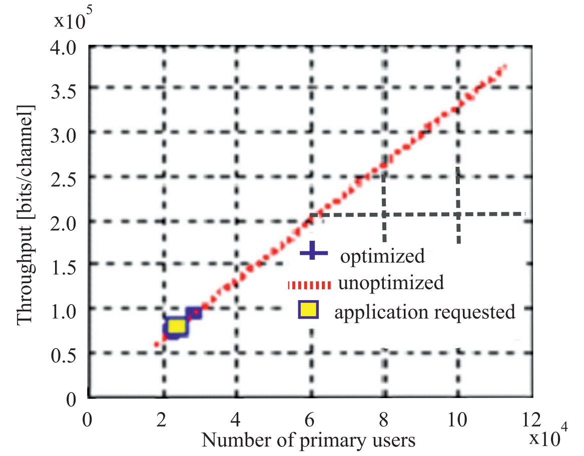

Fig. 3. Variation of throughput with number of primary users.

Figures 3 and 4 show the GA optimized plots of throughput and spectral efficiency for the application requested value considered. After the GA execution throughput is 79725.29 bits/channel for application requested decimal

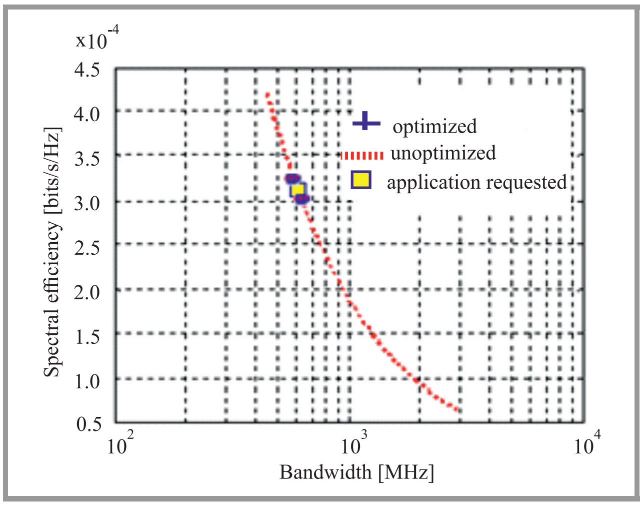

Fig. 4. Variation of spectral efficiency with bandwidth.

value 4. The exact value of the corresponding number of primary user is 24000, which is very close to the actual value 79726.28 bits/channel. Having application requested decimal value 4 it can be rounded up 79726 bits/channel resulting spectral efficiency 0.000312 for application requested decimal value 4. The exact value of the corresponding bandwidth is 607.638 MHz, and can be rounded up to 608 MHz, which corresponding to application requested value of bandwidth 16.

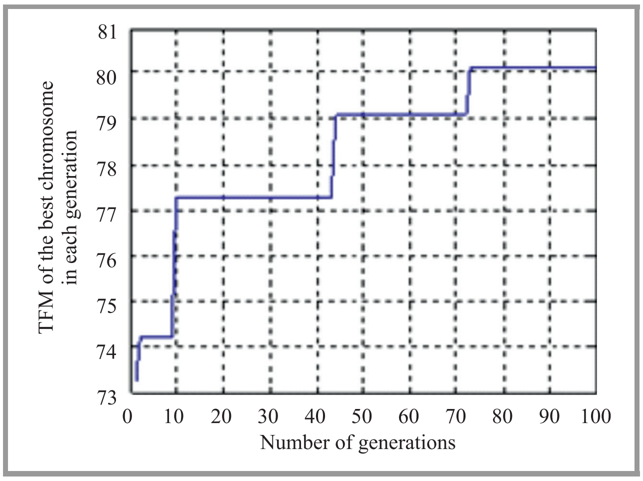

Fig. 5. Variation of TFM of the best chromosome with number of generations.

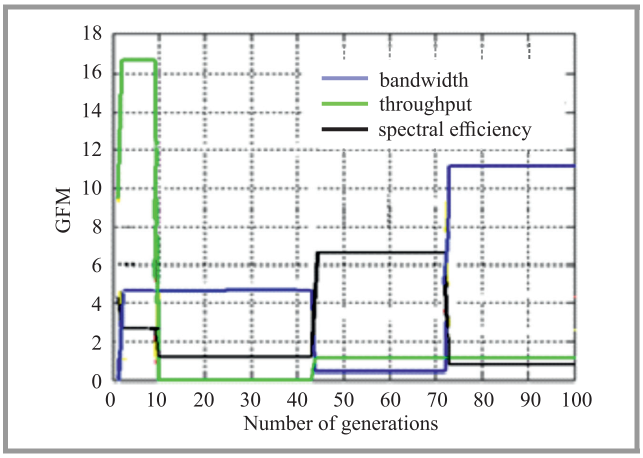

Fig. 6. Variation of GFM of Gene 1, Gene 2, and Gene 3 with number of generations.

In case 2 the used application requested decimal values are: bandwidth = 46, throughput = 12, spectral efficiency = 56, initial population = 100, maximum generations = 100.

Figures 5 and 6 show the TFM and GFM of the adaptive GA.

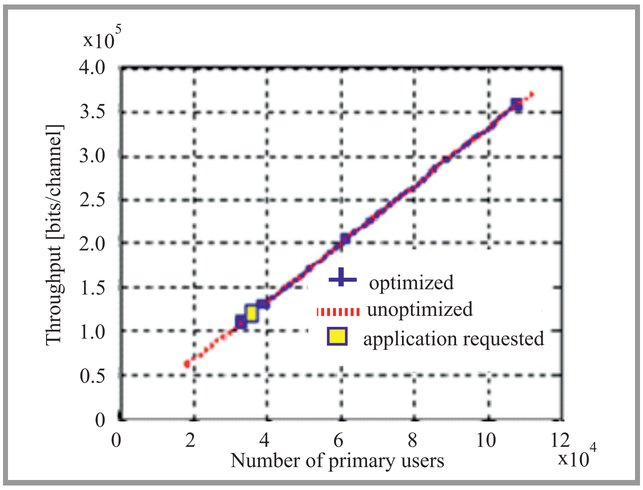

Fig. 7. Variation of throughput with number of primary users.

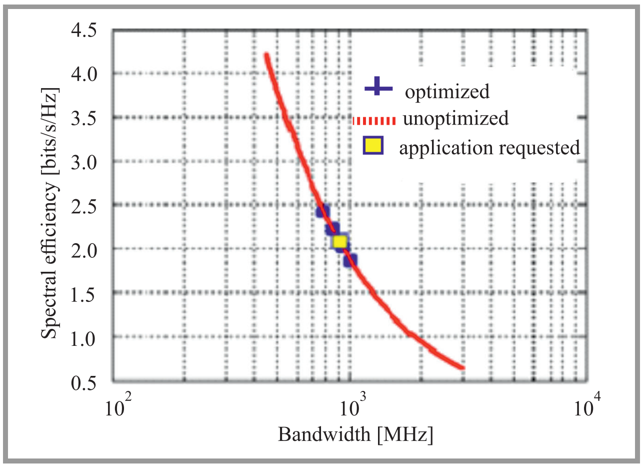

Fig. 8. Variation of spectral efficiency with bandwidth.

Figures 7 and 8 show the GA optimized plots of throughput and spectral efficiency for the application requested value considered. After the execution of GA. Throughput is 119589.41 bits/channel and spectral efficiency is 0.000208 for application requested decimal value 56. The exact value of the corresponding bandwidth is 911.45 MHz and very close to 910 MHz corresponding to application requested value of bandwidth 46. The deviation is around 1 MHz.

Case 3 uses the application requested decimal values: bandwidth = 72, throughput = 19, spectral efficiency = 79, initial population = 100, maximum generations = 100.

Figures 9 and 10 show the TFM and GFM of the adaptive GA for this simulation set.

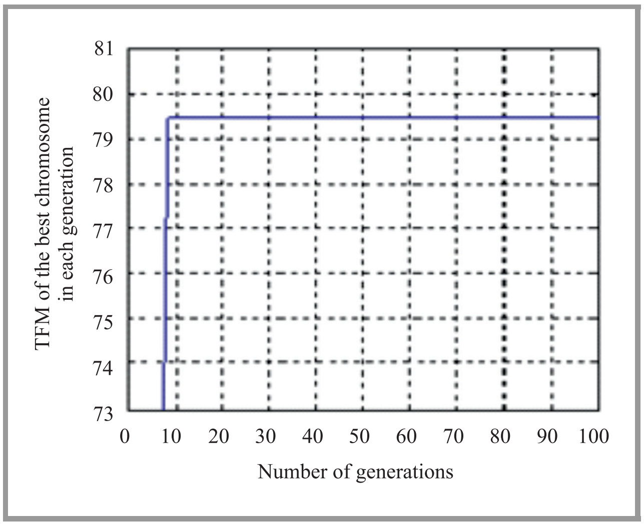

Fig. 9. Variation of TFM of the best chromosome with number of generations.

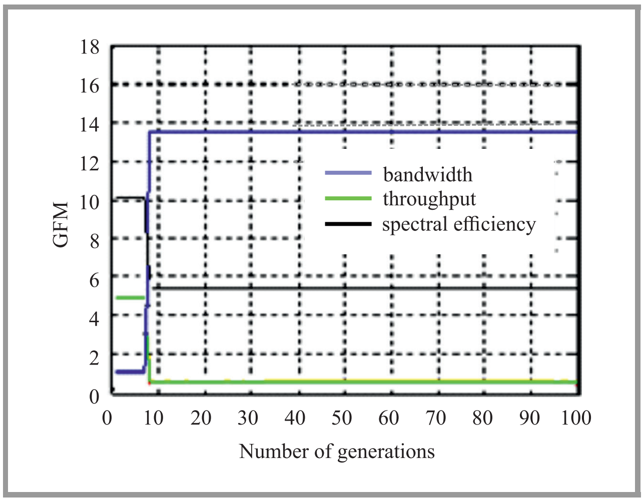

Fig. 10. Variation of GFM of Gene 1, Gene 2, and Gene 3 with number of generations.

Figures 11 and 12 show the GA optimized plots of throughput and spectral efficiency for the application requested value considered. After GA is executed, the spectral efficiency 0.0001637 was received for application requested decimal value 79 and the exact value of the corresponding bandwidth is 1170.26 MHz instead of the actual value of the bandwidth 1170 MHz, which corresponding to application requested value of bandwidth 72. The deviation is of 0.26 MHz.

In addition the throughput 154469.656 bits/channel was achieved whereas the exact value is 154469.66 bits/channel, which can be rounded to 154470 bits/channel and the exact value of the corresponding number of primary user is 46500.

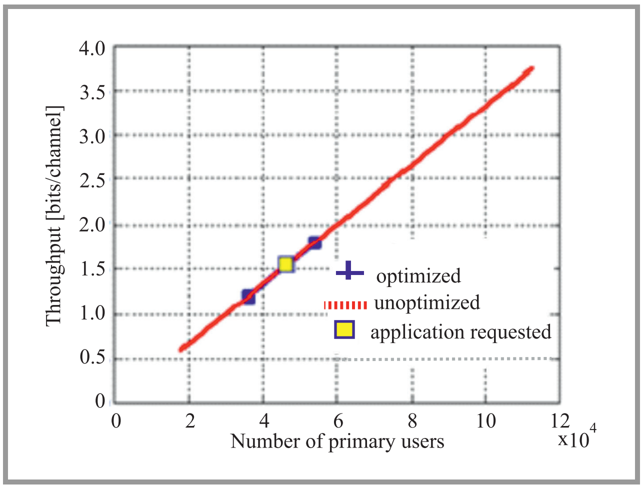

Fig. 11. Variation of throughput with number of primary users.

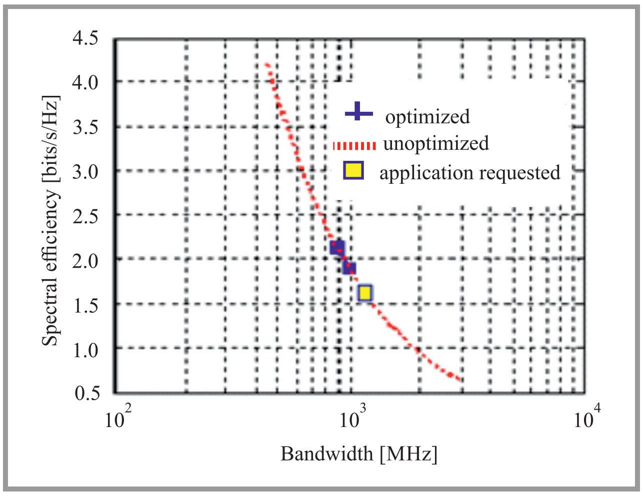

Fig. 12. Variation of spectral efficiency with bandwidth.

Comparing Figs. 1 to 12 for all the different sets of application requested decimal value and the discussion shows that maximum percentage deviation from the actual value is around 0.1. The deviations noticed are due to the randomness and can be minimized/eliminated by several executions techniques. The aim of the work is to propose a demand based GA by considering different regions of the spectrum and optimizing the sensing parameters considering the time varying nature of the spectrum and comparison theoretically calculated values with the values after execution of the GA.

6. Conclusion

The simulation results shows that the proposed method gives better real life solution to the cognitive system as time varying nature of spectrum hole is considered and having capability of adaption with the varying nature of spectrum holes.

References

[1] J. Elhachmi and Z. Guennoun, "Cognitive radio spectrum allocation using genetic algorithm", *EURASIP J. on Wirel. Commun. and Netw.*, vol. 2016, pp. 133–143, 2016 (doi: 10.1186/s13638-016-0620-6).

[2] S. Chatterjee, J. S. Roy, and P. P. Bhattacharya, "Spectrum sensing techniques for cognitive radio – a survey", *Int. J. of Appl. Engin. Res.*, vol. 10, no. 7, 2015, pp. 16665–16684.

[3] R. Deka, S. Chakraborty, and J. S. Roy, "Optimization of spectrum sensing in cognitive radio using genetic algorithm", *Facta Universit., Ser: Elec. Energ.*, vol. 25, no. 3, pp. 235–243, 2012 (doi: 10.2298/FUUEE1203235D).

[4] M. J. Kaur, M. Uddin, and H. K Verma, "Optimization of QOS parameters in cognitive radio using adaptive genetic algorithm" *Int. J. of Next-Gener. Netw.*, vol. 4, no. 2, pp. 1–15, 2012.

[5] J. Ramesh and A. Raman, "Optimization of sensing parameters using PSO, GA for cognitive radio", *Recent Trends in Sensor Res. & Technol.*, vol. 2, no. 3, pp. 23–30, 2015.

[6] P. T. A. Quang, S. R. Kim, and D. S. Kim, "A throughput-aware routing for distributed industrial cognitive radio sensor networks", in *Proc. 9th IEEE Int. Worksh. on Factory Commun. Syst. WFCS 2012*, Detmold, Germany, 2012, pp. 87–90.

[7] T. T. Le, and D.-S. Kim, "An efficient throughput improvement through bandwidth awareness in cognitive radio networks", *J. of Commun. & Netw.*, vol. 16, no. 2, pp. 146–154, 2014 (doi: 10.1109/JCN.2014.000025).

[8] S. Kaur and I. K. Aulakh, "Optimization of cognitive radio sensing techniques using genetic algorithm", *Int. J. of Innov. Res. in Comp. & Commun. Engin.*, vol. 3, no. 5, pp. 4131–4139, 2015 (doi: 10.15680/ijircce.2015.0305104).

[9] I. F. Akyildiz, W. Y. Lee, and K. R. Chowdhury, "Spectrum management in cognitive radio ad hoc networks", *IEEE Network*, vol. 23, no. 4, pp. 6–12, 2009.

[10] A. Marţian, C. Vlădeanu, I. Marcu, and I. Marghescu, "Evaluation of spectrum occupancy in an urban environment in a cognitive radio context", *Int. J. on Adv. in Telecommun.*, vol. 3, no. 3–4, pp. 172–181, 2010.

[11] M. Lopez-Benitez *et al.*, "Spectral occupation measurements and blind standard recognition sensor for cognitive radio networks", in *Proc. 4th Int. Conf. on Cognitive Radio Oriented Wireless Networks & Commun. CrownCom 2009*, Hannover, Germany, 2009, pp. 1–9.

[12] X. Meng, S. Wu, L. Kuang, D. Huang, and J. Lu, "Multi-user detection for spatial modulation via structured approximate message passing", *IEEE Commun. Lett.*, vol. 20, no. 8, pp. 1527–1530, 2016 (doi: 10.1109/LCOMM.2016.2577627).

Subhajit Chatterjee is an Assistant Professor in the Department of Electronics & Communication Engineering, University of Engineering & Management, Kolkata, West Bengal, India. His research interests include signal processing, wireless network and cognitive radio. Currently he is a registered Ph.D. scholar at KIIT University, Bhubaneswar, Odisha, India.

E-mail: chsubhajitch@gmail.com
Department of Electronics
and Communication Engineering
University of Engineering & Management
Kolkata, West Bengal, India

Swaham Dutta is working in the capacity of Assistant Manager in Big Data Analysis division, Relience Jio Infocomm Ltd., Mumbai, and Maharashtra, India. He has completed the B.Tech. degree from West Bengal University of Technology, Kolkata, India. His research interests are wireless sensor network, data processing and cognitive radio.

E-mail: swahamd@gmail.com
Reliance Jio Infocomm Ltd.
Big Data Analysis
Mumbai, Maharashtra, India

Partha Pratim Bhattacharya is working as Professor in Department of Electronics and Communication Engineering in the College of Engineering and Technology, Mody University of Science and Technology (formerly, Mody Institute of Technology and Science), Rajasthan, India. His present research interest includes mobile cellular communication, wireless sensor network and cognitive radio. He is a member of The Institution of Electronics and Telecommunication Engineers, India and The Institution of Engineers, India. He is working as reviewer in many reputed journals like IEEE Journal on Selected Areas in Communications, IET Communications, Springer's IEIB, Elesevier's Computer Communication, Elsevier's Journal of Network and Computer Applications, Adhoc and Sensor Wireless Networks, Annals of Telecommunications – Annales des Télécommunications, Elsevier's Physical Communication, Indian Journal of Science and Technology, etc.

E-mail: hereispartha@gmail.com
Department of Electronics and Communication
Engineering
College of Engineering and Technology
Mody University of Science and Technology
Lakshmangarh – 332311, Rajasthan, India

Jibendu Sekhar Roy is a Professor in the School of Electronics Engineering, KIIT University, Bhubaneswar, Odisha, India. From 1998 to 2009, he was lecturer, reader and professor in the ECE department of Birla Institute of Technology, Mesra, Ranchi, India. He has received Ph.D. degree from the Department of Electronics & Telecommunication Engineering, Jadavpur University, Calcutta, India in 1991. From 1991 to 1993, he was a post-doctoral research associate of CNRS, Govt. of France in IRCOM, University of Limoges, France. From 1994 to 1998, he was a research associate of CSIR in ETCE department, Jadavpur University, Calcutta. His research interest includes microwave and millimeter wave antennas for wireless communication, optimization of thinned array antenna, smart antennas, channel assignment & MIMO-OFDM algorithms, cognitive radio.

E-mail: drjsroy@rediffmail.com
School of Electronics Engineering
KIIT University
Bhubaneswar, Odisha
India