Defence Science Journal, Vol. 68, No. 3, May 2018, pp. 295-299, DOI : 10.14429/dsj.68.11758

Energy-efficient Multiple Relay Selection in Cognitive Radio Networks

Yamuna K. Moorthy*, Sakuntala S. Pillai, and G. Shiny

Mar Baselios College of Engineering and Technology, Trivandrum – 695 015, India

**E-mail :yamunakmoorthy@gmail.com*

ABSTRACT

Cognitive Radios play very important role in military applications due to their capability to adapt intelligently according to the prevailing environmental conditions. Relays form the main communication enablers in infrastructure-less networks. In this paper, relay selection for increasing the energy efficiency of a cognitive radio network is considered. The proposed approach considers the multiple - relay selection scheme with strict outage probability constraints. Energy maximisation is posed as an optimisation problem, the solution to which shows that relay selection under outage constraints is different from the one without such a constraint. It can be observed from the simulations that energy efficiency and outage behaviour follows trade-off relations. Moreover, the original Branch and Bound algorithm has been re-designed for faster convergence. It has also been demonstrated that when strict outage constraints are imposed, the optimal number of relays selected will be more in comparison to the case where there is no outage consideration.

Keywords: Cognitive radio; Energy-efficiency; Branch and bound; Fractional programming; Outage probability

1. INTRODUCTION

The continuously growing wireless applications have made the present day cell phone users more demanding of data rate, speed and quality of service (QoS). The subsequent spectral inadequacy severely affects wireless applications in military, commercial and civil sectors. However, FCC[1] reports that most of the licensed spectrum is currently either unused or under-utilised. Cognitive radio (CR) technology is one of the state-of-the-art technologies which was originally proposed to mitigate the spectral inadequacy problem. CRs exploit un-utilised and underutilised frequency bands of the licensed users through sensing and subsequent dynamic sharing of spectrum with unlicensed users. An overview of the major developments in the area of CRs is as given in articles[2-4].

There is a call for the wireless domain to go 'green' due to various reasons[5]. One is to increase the battery life of wireless devices especially in highly restricted and military areas[6]. Second reason is to reduce the greenhouse gas emissions due to wireless devices. In addition, radiations from wireless terminals pose serious threats to human beings and other living creatures. Energy efficiency (EE) has thus become a parameter of paramount importance in military and civilian wireless communications. The idea of green communications using CR systems has been described by Grace[7] , *et al.* Some of the major benefits of using CRs for energy efficient communications are provided in the works of Alag[8], *et al.* and Sanctis[9], *et al.*

Relay-assisted communication exploits spatial diversity in wireless environment for improving spectral efficiency. From an EE perspective too, relays are highly beneficial[10]. This is mainly due to less transmitted power required by relay nodes which leads to prolonged battery life.

In the proposed work, authors implemented a novel multiple relay selection in a CR network where SUs and PUs co-exist. The goal is to maximise the EE of the secondary network under preset transmit power, interference and outage constraints. Even though present work is somewhat similar to that of He[11], *et al.* it stands far apart in that the proposed work arrives at the best relay set based on outage behaviour. On the other hand, reference cited above selects relay based on the data rate requirements and thereafter the outage behaviour is analysed. Furthermore, in the proposed work, the authors have formulated the optimisation problem as a combinatorial integer programming problem which is fractional in nature. The original problem is mathematically intractable and therefore a sub-optimal algorithm is also designed which is a modified version of the classical branch and bound (BnB) algorithm. To the best of the authors' knowledge a similar study has not been conducted so far. Simulation and numerical results demonstrate that the proposed method achieves the maximum EE compared to existing works.

2. EXISTING WORKS

Jing[12], *et al.* proposed a method for selecting the best relays for maximised throughput. Tang[13], *et al.* proposed best relay criterion jointly with a power allocation procedure for maximising the EE of a CR system. In this work, the energy states at each relay node have been modelled as a finite Markov Chain and the analysis is carried out. Chen[14], *et al.* proposed a joint relay selection and power allocation is performed in a

Received : 02 August 2017, Revised : 22 December 2017
Accepted : 22 January 2018, Online published : 16 April 2018

spectrum leasing scenario. Here, the goal is to select best relay set for the PU and optimally allocate power so as to maximise the weighted sum energy efficiency (WSEE) of the secondary network. Another contribution[15] discusses multiple relay selection scheme to maximise the signal to noise ratio of the CR receiver in a two-hop relay network. This work has considered the interference due to SUs on PUs while formulating the optimisation problem. However, outage probability behaviour is not taken care of in this work. Jing[11], *et al.* proposed a relay selection method based on achievable data rate. However, in the above contribution, the authors have not proposed a general method to select relays considering outage in advance. This motivates us for the proposed work.

3. SYSTEM MODEL AND PROBLEM FORMULATION

In this work, the authors consider a relay assisted CR network, where PUs and SUs co-exist. The network architecture is as depicted in the Fig. 1. The primary and the secondary networks consist of their own transmitters and receivers designated as shown in the figure. The communication between the ST and the SD is aided through cognitive relays SR_i , where $i = 1, 2 \ldots\ldots M$. All the nodes in the network are single antenna equipped. The channels are designated as shown in Fig. 1.

It is assumed that SR and SD are separated by a fading channel. Also, the channel state information (CSI) regarding the ST-relay link is known at the ST and that regarding the relay-SR link and relay-PR link is known at the relays. The channel gains are Gaussian distributed. The noise at both PR and SR is also Gaussian, having zero mean and a variance of N_0 . The relaying protocol used is amplify and forward (AF). Communication between the ST and the SD happens in two consecutive time slots. On the other hand, PT keeps on transmitting continuously. During the first slot, all relays seek information from ST as well as from PT and during the second slot, the selected relay SR_i (hereafter r_i) will forward the received signal to ST.

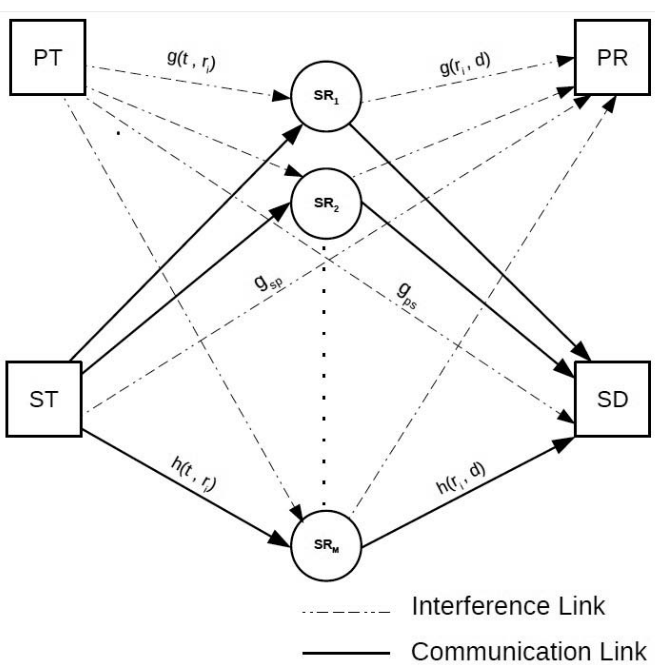

Figure 1. System model for the cognitive relay network.

3.1 Energy Efficient Relay Selection

Let x_p and x_s denote the transmitted signals of PT and STs respectively and the corresponding transmit powers be P_P and P_S . The received signal y_{r_i} at the relay r_i (SR_i) in the first time slot can be expressed as

$$y_{r_i} = \sqrt{P_T}\, g_{t,r_i} x_p + \sqrt{P_S}\, h_{t,r_i} x_s + n_{r_i} \tag{1}$$

where g_{t,r_i} refers to the channel gains from the PT to the i^{th} relay r_i and h_{t,r_i} refers to the channel gains from ST to the i^{th} relay r_i .

The signal transmitted during the first time undergoes an amplification at each relay to produce the signal $y_{r_i}^{AF}$, which is expressed as

$$y_{r_i}^{AF} = \sqrt{P_{R_i}}\, y_{r_i} h_{eq}^{AF} \tag{2}$$

where h_{eq}^{AF} is the equalising gain provided by the relays for compensating the subsequent channel loss. Therefore, it is appropriate to choose $h_{eq}^{AF} = h_{r_i,d}^{*}$ $.P_{R_i}$ denotes the transmit power of the i^{th} relay. At the end of the second time slot, the signal received at the CR receiver can be expressed as[16]

$$y_d = \sum_{i \in M} \begin{bmatrix} \sqrt{P_T}\ P_{R_i}\, g_{t,r_i} x_p \left|h_{r_i,d}\right|^2 + \\ \sqrt{P_S}\, P_{R_i}\, h_{t,r_i} x_s \left|h_{r_i,d}\right|^2 + \\ \sqrt{P_{R_i}} \left|h_{r_i,d}\right|^2 n_{t,r_i} \end{bmatrix} + \sqrt{P_P}\, g_{ps} x_p + \sum_{i \in M} n_{r_i,d} \tag{3}$$

The achievable throughput for the entire end to end communication is given by

$$R = 0.5 \log_2 \left(1 + \max_{i \in M} SINR_i\right) \tag{4}$$

where the $SINR_i$ is as given by Eqn. (5). The signal component S , noise component N and the interference component I can be expressed as:

$$SINR_i = \frac{\sqrt{P_S}\, P_{R_i}\, h_{t,r_i} x_s \left|h_{r_i,d}\right|^2}{\sqrt{P_T}\ P_{R_i}\, g_{t,r_i} x_p \left|h_{r_i,d}\right|^2 + \sqrt{P_P}\, g_{ps} x_p + \sqrt{P_{R_i}} \left|h_{r_i,d}\right|^2 n_{t,r_i} + n_{r_i,d}} \tag{5}$$

$$S = \sqrt{P_S}\, P_{R_i}\, h_{t,r_i} x_s \left|h_{r_i,d}\right|^2 \tag{6}$$

$$N = \sqrt{P_{R_i}} \left|h_{r_i,d}\right|^2 n_{t,r_i} + n_{r_i,d} \tag{7}$$

$$I = \sqrt{P_T}\ P_{R_i}\, g_{t,r_i} x_p \left|h_{r_i,d}\right|^2 + \sqrt{P_P}\, g_{ps} x_p \tag{8}$$

Now EE is calculated by Eqn. (9).

$$\eta_{EE} = \frac{R}{P_{total}} \tag{9}$$

where

$$P_{total} = 2P_P + P_s + \alpha_i P_R \qquad i \in M \tag{10}$$

The term $2P_p$ appears because the PUs keep on transmitting over both the slots.

Equation (3) is re-written as follows in order to make it suitable for optimisation,

$$y_d = \alpha_i \left\{ \begin{array}{l} \sqrt{P_T}\ P_{R_i}\ g_{t,r_i} x_p \left|h_{r_i,d}\right|^2 \\ +\sqrt{P_S}\ P_{R_i}\ h_{t,r_i} x_s \left|h_{r_i,d}\right|^2 \\ +\sqrt{P_{R_i}} \left|h_{r_i,d}\right|^2 n_{t,r_i} + n_{r_i,d} \end{array} \right\} + \sqrt{P_P}\ g_{ps} x_p \tag{11}$$

where $\alpha_i = 1$, when the i^{th} relay i is selected and $\alpha_i = 0$, if it is not selected. Now, the problem of optimal relay selection can be formulated as given follows:

$$\acute{\boldsymbol{a}}^* = \arg\max_{\acute{a}}\ \eta_{EE} \tag{12}$$

$$C_1 : s.t.\ \alpha_i \in \{0,1\} \tag{13}$$

$$C_2 : 2P_P + P_s + \alpha_i P_R \le P_{max} \tag{14}$$

$$C_3 : \sum_{i\in M} P_{R_i} \left|g_{r_i,d}\right|^2 + P_s\, g_{sp} \le I_{th} \tag{15}$$

$$C_4 :\ \Pr\left\{\gamma \le 2^{R_0} - 1\right\} \le P_{out} \tag{16}$$

where I_{th} is the interference threshold limit at the PR and P_{max} is the average power which is available for transmission. The first constraint is about the selection of relays. The second constraint puts an upper limit on the transmission power budget. The third constraint restricts the interference from the ST as well as the selected relays at the PR. The final constraint is regarding the outage probability of the secondary network. γ denotes the least SNR required to enable transmission without an outage and R_0 stands for the required minimum throughput for a given outage probability.

3.2 Solution to the Optimisation Problem

The problem of relay selection is a non-convex optimisation problem which is Knapsack-like and NP-hard. In addition, the energy efficiency function is fractional in nature. Usually, Integer/Combinatorial problems are solved by using Branch and Bound (BnB) methods, but may take an exponential number of iterations, only with a worst case possibility of solving 2^n, where n is the number of variables. In this work, the authors have considered the BnB algorithm for the selection of relays[17]. The original BnB method is slightly modified in this work, since the problem at hand involves binary integers. The algorithm stands apart from other algorithms of the same genre in that it has the advantage of not requiring non-integral relaxations. While the conventional method of enumeration technique might work well with very less number of relays say around 5, the modified methods work well with very huge numbers.

In the modified BnB method, we always maintain the 0-1 integral restrictions, whereas the inequality constraints are ignored temporarily. Towards this end, we first fix some of the variables as 0 or 1. The remaining variables are the free variables. The feasibility is checked for each iteration. The following Table 1. illustrates the modified BnB algorithm as applied to the relay selection procedure.

Table 1. Algorithm for relay selection based on modified BnB

Input output	$P_{max}, I_{th}, P_{out}\ \ \acute{\boldsymbol{a}}^*, \eta_{EE}$
1.	Randomly select any one α_i
2.	Set *k=1*
3.	Branch w.r.t to 2 subspaces corresponding to $\alpha_i^k = 1$ and $\alpha_i^k = 0$, ignoring the inequality constraints and set other variables $\alpha_j \in \{0,1\}^{M-k}$, $j = 1, 2, \ldots\ldots, M$, $j \ne i$ as free variables.
4.	Check the feasibility of the solution corresponding to $\alpha_i^k = 1$ and $\alpha_i^k = 0$ by considering the inequality constraints (Possibilities are either of the one will be feasible or both)
5.	Proceed with the value of α_i^k (0 or 1) for which the solution is feasible.
6.	If both (0 and 1) are feasible, select the one with the maximised objective function.
7.	k = k+1
8.	Select the next variable.
9.	Repeat steps 2-7 until *k=M*

4. SIMULATION AND NUMERICAL RESULTS

Authors validated the proposed algorithm through simulations. The range of values for all the plots are selected in such a way that they clearly portray the trend in the desired region. All throughout the simulations, we assume that the channels are Rayleigh distributed. The relays are placed at random locations roughly in a circular area. The number of relays range from a minimum of 1 to maximum of 20. The maximum transmit power P_{max} = 10 dBm and Interference threshold I_{th} = 20 dBm. The rate R_0 which decides the outage probability is taken to be 0.5 bits/s. The results are obtained after averaging over 10,000 simulations. For simplicity, we have performed water filling power allocation for all the relays. For comparison, we have adopted the Greedy Spectrum Sharing (GSS) -based best set relay selection[15]. In addition, the modified BnB algorithm exhibits a very good guarantee of convergence, which is verified through extensive simulations. For instance, for 10 relays, the algorithm converges in 2-3 iterations, for 20 relays, the algorithm converges in 5-6 iterations and for a relay set of 30, the algorithm converges in 8-9 iterations on an average.

In Fig. 2, the EE curves for different values of PU interference thresholds are plotted for GSS based selection[15], random relay selection and relay selection according to the proposed BnB method. It is demonstrated that the proposed method performs better than the other two. It is obvious that EE function follows a uni-modal variation with respect to the interference threshold I_{th}. This is due to the fact that, elevating the threshold of PU interference means that ST can transmit with more power, which eventually leads to successful receptions at the SR end. Thus, EE follows an increasing trend till a particular value of I_{th}. On the other hand, making the SU transmissions liberal by permitting the higher value of interference threshold would adversely affect both the SU and PU QoS, thereby decreasing EE. As far as the SU network is concerned, this is

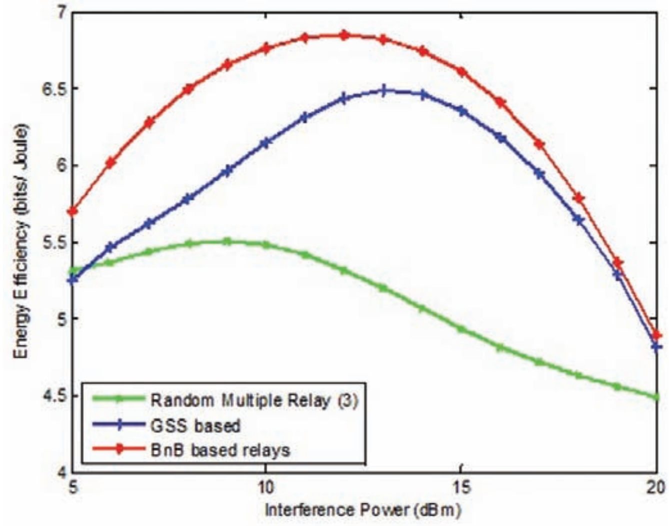

Figure 2. EE vs. Interference threshold at the PU for various schemes.

due to the growing interference among SU nodes. Therefore a declining trend for EE can be observed at higher values of I_{th} . It also provides the insight that this method can tolerate more interference power at the PU, compared to many existing methods.

In Fig. 3, EE vs. available number of relays is plotted. It is clear that as the number of available relays increase there will be slight drop in energy efficiency, since chances are high that more relays participate in transmission. In addition, it is observed that, when the outage probability constraints are removed, EE increases, but at the cost of poor reliability.

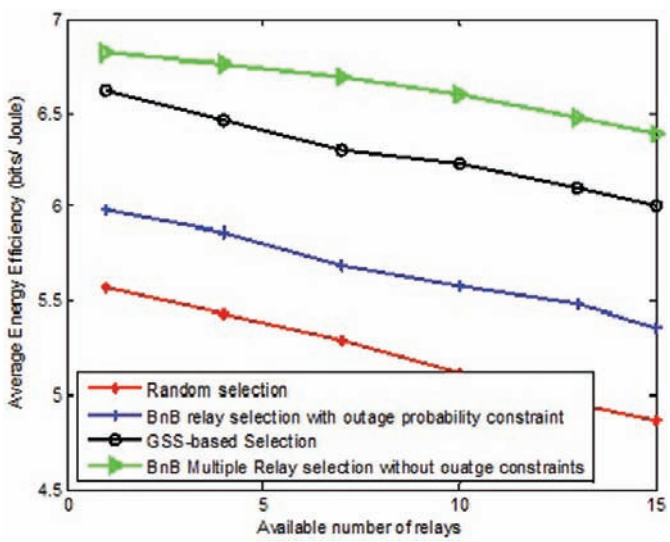

Figure 3. Energy efficiency with respect to number of available relays.

Fig. 4 is a plot of average EE vs. outage probability thresholds. It is clearly understood that as the outage probability constraints become more stringent, EE decreases. However, on making the outage probability threshold loose, EE increases. This is because, in the second case, number of relays participating would be less. The reverse happens when the outage probability constraints are tight.

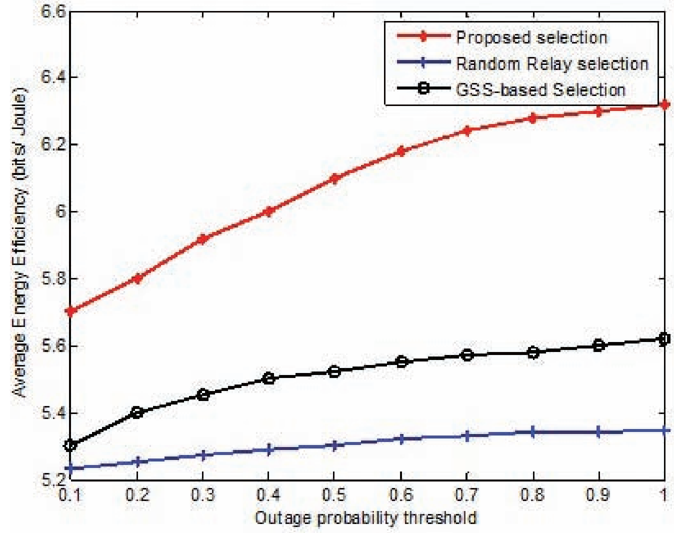

Figure 4. EE w.r.t. outage probability for various schemes.

In Fig. 5, the authors have plotted the probability of selecting a particular relay set against the cardinality of the relay set. It can be noticed that, given no outage constraint, the maximum probability is for selecting a single relay. Relay sets with higher cardinality are seldom selected, their probability tending to zero for a set even with cardinality 4.

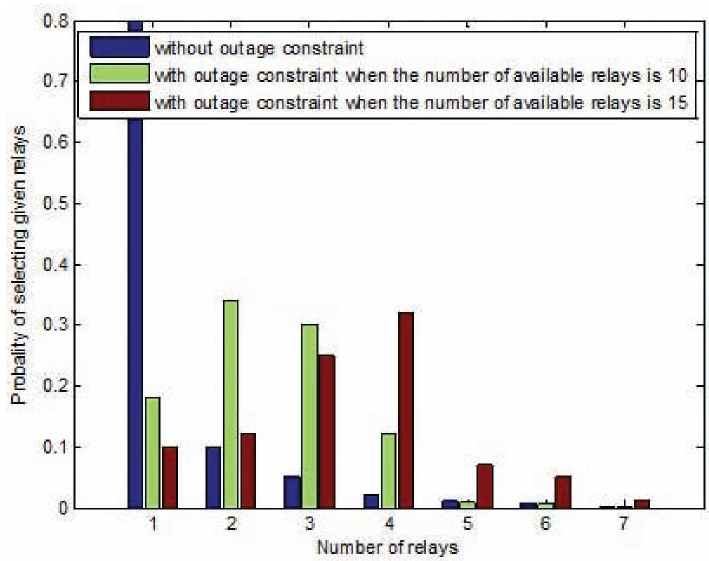

Figure 5. Probability of selecting a relay set vs. its cardinality.

5. CONCLUSIONS

In this paper, a novel relay selection method to maximise energy efficiency is proposed. A modified branch and bound algorithm was also developed for solving the 0-1 combinatorial relay selection problem. The relay selection takes outage probability into consideration while the optimisation is being performed. Simulation and numerical results show that this method has resulted in higher energy efficiency than the already existing GSS method and random selection of relays. Furthermore, the simulations show that selection of relay nodes with outage probability constraints calls for more selected relays. As a future work the authors aim to derive an analytical expression for the upper bound of energy efficiency achievable in our scenario.

REFERENCES

1. Federal Communications Commission. Spectrum policy task force. ET Docket 02-135, November 2002.
2. Mitola, J. & Maguire, G.Q. Cognitive radio: Making software more personal. *IEEE Personal Comm.*, 1999, **6**(4), 13-18.
3. Haykin, S. Cognitive radio: Brain-empowered wireless communication. *IEEE J. Sel. Areas Comm.* 2005, **23**, 201-220
4. Ghasemi, A. & Sousa, E.S. Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs. *IEEE Commun. Mag.*, 2008, **46**(4), 32-39
5. Smart2020: Enabling the low carbon economy in the information age, The Climate Group SMART2020 Report.
6. Perumal, P. Shunmuga; Uthariaraj, V. Rhymend & Christo, V.R. Elgin. Intelligent UAV-assisted localisation to conserve battery energy in military sensor networks. *Def. Sci. J.*, 2014, **64**(6), 557-563.
   doi: 10.14429/dsj.64.5295
7. Grace, D.; Chen Tao Jiang, J. & Mitchell, P.D. Using cognitive radio for delivering green communications. *In* Proceedings of 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications, Hannover, 2009, pp. 1-6.
   doi:10.1109/CROWNCOM.2009.5189203
8. Gür, G. & Alagöz, F. Green wireless communications via cognitive dimension: An overview. *IEEE Network*, 2011, **25**(2), 50-56.
   doi: 10.1109/MNET.2011.5730528
9. De Sanctis, M.; Cianca, E. & Joshi, V. Energy efficient wireless networks towards green communications. *Wirel. Pers. Commun.*, 2011, **59**(3), pp. 537–552.
10. Buzzi, S.; C.-L. I,; Klein, T.E.; Poor, V.; Yang, C. & A. Zappone. A survey of energy-efficient techniques for 5G networks and challenges ahead. *IEEE J. Sel. Areas Comm.*, 2016, **34**(4), pp. 697-709.
    doi: 10.1109/JSAC.2016.2550338
11. He, J.; Guo, S.; Wang, F. & Yang, Y. Relay selection and outage analysis in cooperative cognitive radio networks with energy harvesting. *In* IEEE International Conference on Communications (ICC), Kuala Lumpur, 2016, pp. 1-6.
    doi: 10.1109/ICC.2016.7511240
12. Jing, T.; Shixiang, Z.; Hongjuan, L.; Xiuzhen, C. & Yan, H. Cooperative relay selection in cognitive radio networks. *IEEE Trans. Vehicular Technol.*, 2015, **64**(5), 1872-1881.
    doi: 10.1109/TVT.2014.2338297
13. Tang, D.; Jiang, D.; Huang, G. & Xia, M. Energy states aided relay selection and optimal power allocation for cognitive relaying networks. *IET Comm.*, 2017, **11**(7), 1045-1052.
    doi: 10.1049/iet-com.2016.0832
14. Chen, J.; Lv, L.; Liu, Y.; Kuo, Y. & Ren, C. Energy efficient relay selection and power allocation for cooperative cognitive radio networks. *IET Communications*, 2015, **9**(13), 1661-1668.
    doi: 10.1049/iet-com.2014.1246
15. Xu, J.; Zhang, H.; Yuan, D.; Jin, Q. & Wang, C.X. Novel multiple relay selection schemes in two-hop cognitive relay networks. *In* 3rd International Conference on Communications and Mobile Computing, Qingdao, 2011, pp. 307-310.
16. Chen, G.; Zhon, W.; Tian, H.; Xie, W. & Chen, Y. Best relay selection with interference power constraint in cognitive relay networks. *In* Proceedings of 2nd International Conference on Computer Science and Network Technology, Changchun, 2012, pp. 98-102.
    doi: 10.1109/ICCSNT.2012.6525899
17. Lawler, E. & Wood, D. Branch-and-bound methods: A survey. *Operations Research*, 1966, **14**(4), 699-719.

CONTRIBUTORS

Ms Yamuna K. Moorthy received her BTech (Electronics and Communication Engineering) from Govt. Engineering College, Barton Hill, Trivandrum and MTech (Signal Processing) from College of Engineering, Trivandrum. Currently pursuing her PhD in the area of Energy Efficiency in Cognitive Wireless Networks. Since 2016, she is with Central Polytechnic College, Trivandrum under the Department of Technical Education, Govt. of Kerala.
In the current study, She has done coding and manuscript writing. She also developed the modified Branch and Bound algorithm which is suitable for relay selection problem of the same nature.

Dr Sakuntala S. Pillai received BTech (Telecommunication Engineering), MTech (Microwave Engineering) from College of Engineering, Trivandrum and PhD from University of Kerala. Currently working in the Department of Electronics & Communication, Mar Baselios College of Engineering & Technology, Trivandrum. Her research interests include OFDMA, MIMO wireless systems, error correction coding, speech coding.
In the current study, she gave the idea of relay selection for enhancing the energy efficiency of a Cognitive Radio network.

Dr Shiny G. received her BTech (Electronics and Communication Engineering) from Madurai Kamaraj University, in 1990 and MTech and PhD from the Kerala University, in 1994 and 2013 respectively. Currently, she is a Professor in the Department of Electronics and Communication Engineering, College of Engineering Trivandrum. Her research interests include : power electronics and drives and wireless communication systems.
In the current study, she is mainly involved in monitoring and verifying the results on a periodic basis. Her role in typesetting and bringing the paper in the present form is worth mentioning.