Intelligent Multiple Relay Selection and Transmit Power-Saving with ABC Optimization for Underlay Relay-assisted CRNs

Kiran Sultan[1], Atta-ur-Rahman[2], Bassam A. Zafar[3], Nahier Aldhafferi[2], and Abdullah Alqahtani[2]
[1] Dept. of Computer and Information Technology, King Abdulaziz University, Jeddah, KSA
[2]College of CS and IT, Dept. of CS, Imam Abdulrahman Bin Faisal University, Dammam, KSA
[3]Faculty of Computing & Information Technology, King Abdulaziz University, Jeddah, KSA
Email: kkhan2@kau.edu.sa, aaurrahman@uod.edu.sa, bzafar@kau.edu.sa, {naldhafeeri, aamqahtani}@iau.edu.sa

Abstract —In this paper, a transmit power-saving scheme incorporated with multiple relay-selection for performance enhancement of underlay relay-assisted cognitive radio networks (RCRNs) is proposed. For this purpose, a secondary source assisted by a set of Amplify-and-Forward (AF) cognitive relays to communicate with its intended destination, is considered. The relays operate in half duplex mode below the interference threshold of a primary user (PU). In contrast to the previous relay selection schemes in this context, our proposed technique is focused on the difference of signal-to-noise ratio (SNR) of source-relay and corresponding relay-destination link for each candidate relay and decisions regarding power-saving and SNR maximization are solely based on this factor. However, for the sake of interference-mitigation, multiple relay selection is performed and assigns a selection priority factor for each relay based on SNR of its corresponding relay-destination link. Finally, ease of implementation and quick convergence along with strong exploration and exploitation techniques of Artificial Bee Colony (ABC) algorithm convinced us to employ this global optimizer to achieve the optimum results of our multi-constrained problem. Performance of the proposed scheme is shown through computer simulations.

Index Terms—Cognitive radio network, underlay spectrum sharing, amplify-and-forward, relay networks, artificial bee colony

I. Introduction

Cognitive Radio (CR) with cooperative relaying stand as a well-established and a fascinating combination to combat deep path loss, heavy fading and improve other system's performance parameters using spatial diversity combining [1]-[2]. Thus, relay-assisted cognitive radio networks (RCRNs) have gained remarkable attention in recent years to extend the coverage area of a secondary network in an underlay spectrum sharing approach. However, the major challenge faced by a bunch of potential cognitive relays sharing the licensed spectrum with the licensed or Primary User (PU) is in the form of interference constraint [2]. This limitation places a significant negative impact on the transmit power of the relays which in turn drops end-to-end SNR of the secondary network, and can even cease the secondary communication in the worst scenario. In this context, a variety of solutions have been proposed and accepted by the research community and relay selection lies among the acknowledged methodologies [3].

In underlay RCRNs, relay selection aims to optimize the secondary system's performance while keeping an eye on the peak interference level tolerable to the neighboring PU(s) [4]. Both best and multiple relay selection schemes have been proposed for different selection criterion employing Amplify-and-Forward (AF) [5], Decode-and-Forward (DF) [6] and combination of AF-DF [7] relays. AF relaying is widely used among all relaying protocols due to its comparatively easy implementation and less delay as just amplification is done at the relay network with no decoding [8]. Generally speaking, the existing relay selection schemes can be broadly divided into two categories. First, Opportunistic Relay Selection [9], which takes into account the SNR of both source-relay and relay-destination links and requires perfect knowledge of channel state information (CSI) to select the best relay. Second, Partial Relay Selection [10], which considers SNR of either of the source-relay or relay-destination link for relay-selection and employ fixed-gain relays which simplifies relaying operation without compromising significantly on the performance.

Relay selection problems, either opportunistic or partial, have been formulated for different underlay system models. We have cited only those contributions which considered two-hop RCRNS with all single-antenna terminals in a Rayleigh flat-fade scenario. Under this assumption, the authors considered a single secondary source-destination pair assisted by a set of cognitive relays.

[11]-[14] present best relay selection schemes proposed in the absence of line-of-sight (LoS) path between end nodes in secondary network. The network performance is optimized taking into consideration the interference from the secondary network towards the PU. Similar scenario has been considered by Xu. *et al* [15] to carry out multiple relay selection. However, there are relatively limited contributions in the area of multiple relay selection. [3] performed multiple relay selection while assuming the secondary source being away from PU and its destination. In [16], ElShaarany *et al.* proposed multiple relay selection technique when secondary destination and PU are both assumed to lie under the coverage area of source.

Social insects (wasps, ants, bees etc.) can adapt themselves to the changing environment and build

Manuscript received January 10, 2018; revised June 20, 2018.
Corresponding author's email: kkhan2@kau.edu.sa
doi:10.12720/jcm.13.7.377-384

flexible colonies, which make them capable of maintaining robustness in their life despite unfavorable conditions. This interaction of social insects with each other and their adaptive behavior towards variable environmental conditions has given birth to may Evolutionary Algorithms (EAs) [17]. Bio-inspired EAs such as, Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), simulated Annealing (SA), Bee Colony Optimization (ABC) and Invasive Weed Optimization (IWO) have emerged as a fascinating field for mathematical modelling and optimization of multi-objective and multi-constrained engineering problems using their derivative-free approach. Karaboga's ABC is comparably new population-based global optimizer developed on the foraging behavior of honey bees. The key winning characteristics of ABC are ease of implementation, good balance between exploration and exploitation, fewer control parameters, and fast convergence. ABC has already gained remarkable attention to solve diverse real-world problems in engineering and science [18]-[21]. Different optimization domains of CRNs also employed ABC to solve problems involving interference mitigation [22], spectrum sensing and allocation [23]-[24], and relay selection [25]-[26].

In this proposal, we focused on an underlay RCRN and applied the concept of opportunistic relay selection to select multiple relays aiming to maximize end-to-end SNR. In underlay scenario, the existing relay selection problems are generally formulated based on the end-to-end SNR's bounds of a relay network. Our proposed technique is different from such prior schemes in its unique way to perform transmit-power saving at the relay network before and after relay selection. For this purpose, we take interest in the difference of SNR of each relay's source-relay and corresponding relay-destination link which is the prime novelty of our approach as compared to previous contributions in this context. We suggested a three-phase optimization strategy, first the *power-saving phase* followed by a *relay selection phase* and finally *SNR maximization phase*. Power-saving phase is based on SNR upper bound and aims to achieve maximum cooperative diversity while transmitting only useful power at the relay network, which is a positive step towards interference mitigation as well. Followed by power-saving phase is the relay-selection phase, in which we set precedence of each relay to participate in communication on the basis of its corresponding SNR at relay-destination link. Finally, in SNR maximization phase, we aim to approach SNR upper bound for the selected relays.

The structure of the remaining paper is as follows. In Section II, the system model is described and mathematical problem for multiple relay selection is built. Section III explains the proposed algorithm in detail followed by section IV in which simulation results are provided. Finally, the whole work is concluded in section V.

II. System Model and Problem Formulation

We focus on a dual-hop Cognitive Radio Network (CRN) comprising a secondary source S dependent on $\Psi_{\mathrm{IN}} = \{R_i\}_{i=1}^{I}$ AF relays to communicate with its destination D. The potential relay set is allowed to transmit below the interference threshold of the licensed user Q following the principles of underlay spectrum sharing. The system model is illustrated in Fig.1. Without loss of generality, we make some assumptions in our system model to simplify the analysis. First, LoS path between source-destination pair undergoes deep fading so end-to-end communication solely depends on the intermediate relays. Second, all source-relay, relay-destination and relay-PU links with channel coefficient f_{ab} $\left(a \in \{\mathrm{S}, R_i\},\ b \in \{R_i, \mathrm{Q}, \mathrm{D}\}\right)$ are subject to independent and identically distributed (i.i.d.) Rayleigh flat fading. Third, perfect knowledge about CSI is available. Finally, the PU does not experience interference from the source being physically far apart from each other. The relay network operates in half-duplex mode and end-to-end transmission is completed in two time-slots according to time-division multiple access (TDMA) [27]. In first time slot, the relay network silently listens to the message broadcast by the source with fixed transmit power $\mathrm{P_S}$. In second time-slot, the best subset of relays $\Psi_{\mathrm{S}} \subseteq \Psi_{\mathrm{IN}}$ is selected to amplify and forward the received message to the destination. We declare a subset to be the "best" candidate for selection if it maximizes the end-to-end SNR while strictly obeying the peak interference threshold $\mathrm{I_T}$.

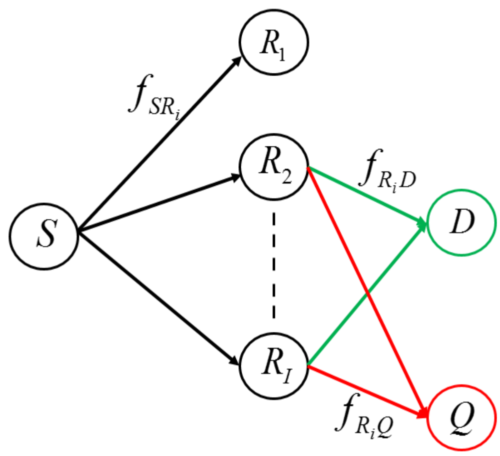

Fig. 1. The system model

The instantaneous end-to-end SNR γ_i of an i^{th} relay-link of a dual-hop AF based relay network has been derived multiple times in literature and is given by [28],

$$\gamma_i = \frac{\gamma_{SR_i}\gamma_{R_iD}}{1+\gamma_{SR_i}+\gamma_{R_iD}} \tag{1}$$

Substituting instantaneous SNR of i^{th} source-relay link $\gamma_{SR_i} = \frac{\mathrm{P_S}\left|f_{SR_i}\right|^2}{N_0}$ and corresponding relay-destination link $\gamma_{R_iD} = \frac{\mathrm{P}_{R_i}\left|f_{R_iD}\right|^2}{N_0}$, the above eq. takes the form,

$$\gamma_i = \frac{\frac{\mathrm{P_S}\left|f_{SR_i}\right|^2}{N_0}\frac{\mathrm{P}_{R_i}\left|f_{R_iD}\right|^2}{N_0}}{1+\frac{\mathrm{P_S}\left|f_{SR_i}\right|^2}{N_0}+\frac{\mathrm{P}_{R_i}\left|f_{R_iD}\right|^2}{N_0}} \tag{2}$$

where, P_{R_i} denotes the transmit power of the i^{th} relay calculated according to AF protocol by adjusting the corresponding gain A_i using the relation, $\mathrm{P}_{R_i} = A_i^2\left(\mathrm{P_S}\left|f_{SR_i}\right|^2 + N_0\right)$, N_0 denotes the variance of the Additive White Gaussian nose (AWGN), which we will normalize for our simulations.

At the destination of our multi-relay network, maximum ratio combining (MRC) is assumed, and total end-to-end SNR γ_D received at the destination due to Ψ_{IN} relays is given by $\gamma_D = \sum_{i\in\Psi_{\mathrm{IN}}}\gamma_i$ .However, Ψ_{IN} might not be able to satisfy $\mathrm{I_T}$, thus, we modify γ_D for our relay selection problem as:

$$\gamma_D = \sum_{j\in\Psi_{\mathrm{S}}}\gamma_j \tag{3}$$

where, Ψ_{S} denotes the selected subset of $J \le I$ relays such that $\mathrm{I}_{\Psi_{\mathrm{S}}} = \sum_{j\in\Psi_{\mathrm{S}}}\mathrm{P}_{R_j}\left|f_{R_jQ}\right|^2 < \mathrm{I_T}$.

Final consideration towards mathematical formulation of our relay selection problem is the maximum allowed transmit power at each relay, which is limited not only by the interference constraint, but also by the power regulations imposed on the battery capacity of each transmitting node. Thus, our multiple relay selection problem takes the following mathematical form:

$$\max\left(\gamma_D = \sum_{j\in\Psi_{\mathrm{S}}}\gamma_j\right)$$
$$s.t.\ \ C_1:\ \mathrm{I}_{\Psi_{\mathrm{S}}} = \sum_{j\in\Psi_{\mathrm{S}}}\mathrm{P}_{R_j}\left|f_{R_jQ}\right|^2 < \mathrm{I_T}$$
$$C_2:\ \ 0 \le \mathrm{P}_{R_j} \le \mathrm{P} \tag{4}$$

C_1 denotes the peak interference constraint and C_2 is the peak transmit power constraint for each relay with maximum allowed transmit power denoted by P.

III. Proposed Algorithm

A. *Proposed Relay Selection Scheme*

Eq. (2) clearly shows that γ_i is a function of P_{R_i} only with all other parameters deterministic in our case. In research literature, γ_i has a more tractable relation in the form of lower and upper bounds, given by $\gamma_i^{LB} \le \gamma_i \le \gamma_i^{UB}$, where, $\gamma_i^{LB} = \frac{1}{2}\min\left(\gamma_{SR_i},\gamma_{R_iD}\right)$ and $\gamma_i^{UB} = \min\left(\gamma_{SR_i},\gamma_{R_iD}\right)$[29]. Since the difference of 0.5 in γ_i^{LB} and γ_i^{UB} does not affect our relay selection technique, so we will make our decisions based on γ_i^{UB}, however, all the three phases can be equally applied using γ_i^{LB}.

We initialize transmit powers of the set of relays $\Psi_{\mathrm{IN}} = \{R_i\}_{i=1}^{I}$. With reference to (2) above, $\left(\gamma_{SR_i},\gamma_{R_iD}\right) > 0$. First, we start with power-saving phase and target those relays for which γ_i is upper bounded by γ_{SR_i}, thus, resulting in $\gamma_i \le \gamma_{SR_i}$. Hence, for all such relays in Ψ_{S} we reduce P_{R_j} to the point where $\gamma_{R_jD} = \gamma_{SR_j}$ is satisfied. This novel idea serves a big purpose, i.e., to achieve full cooperative diversity while saving the transmit power which in turn has a positive impact towards the interference control. Next, we enter into relay-selection phase for interference mitigation in which we follow a greedy approach and deselect the relays in the ascending order of γ_{R_jD} as we consider a relay with $\min\left(\gamma_{R_jD}\right)$ as the least beneficial for secondary communication. Finally, while satisfying peak interference limit $\mathrm{I_T}$, our goal is to achieve SNR upper bound at each selected relay-link. For this purpose, we set the precedence for the selected relays in the ascending order of $\left(\gamma_{SR_j} - \gamma_{R_jD}\right)$. We set this criterion because a relay with $\min\left(\gamma_{SR_j} - \gamma_{R_jD}\right)$ requires least power amplification to approach its SNR upper bound provided favorable channel conditions, thus, standing as a preferred option from the perspective of transmit power saving, interference control and SNR maximization. The proposed algorithm is provided below.

$$\mathit{Inputs}:\mathrm{P},\mathrm{I_T},\mathrm{P_S},N_0,\left\{f_{SR_i},f_{R_iD},f_{R_iQ}\right\}\ \forall i$$
$$\Psi_{\mathrm{S}} = \Psi_{\mathrm{IN}} = \{R_i\}_{i=1}^{I}, J = \mathit{length}(\Psi_{\mathrm{S}}) = I$$

$$\mathrm{P}_{R_{\Psi_{\mathrm{IN}}}} = \mathrm{P}_{R_{\Psi_{\mathrm{S}}}} = \left[\mathrm{P}_{R_i}\right]_{i=1}^{I}, \qquad \forall i$$

$$where,\ \mathrm{P}_{R_i} = A_i^2\left(\mathrm{P}_\mathrm{S}\left|f_{SR_i}\right|^2 + N_0\right)\ and\ 0 \le \mathrm{P}_{R_i} \le \mathrm{P}$$

$$compute\ \gamma_{SR_i}\ and\ \gamma_{R_iD}\ for\ each\ i^{th}\ relay$$

$$//\text{Phase 1: Power Saving Phase}$$

$$for\left(j = 1: J\right) \qquad //\ j \in \Psi_\mathrm{S}$$

$$\quad if\ \left(\gamma_{R_jD} - \gamma_{SR_j} > 0\right)$$

$$\quad\quad reduce\ \mathrm{P}_{R_j}\ s.t.\ \gamma_{R_jD} - \gamma_{SR_j} = 0$$

$$\quad\quad //\ \gamma_j \le \gamma_j^{UB} = \min\left(\gamma_{SR_j}, \gamma_{R_jD}\right)$$

$$\quad end\ if$$

$$end\ for$$

$$//\text{Phase 2: Relay Selection Phase}$$

$$\mathrm{I}_{\Psi_\mathrm{S}} = \sum_{j\in\Psi_\mathrm{S}} \mathrm{P}_{R_j}\left|f_{R_jQ}\right|^2$$

$$while\left(\mathrm{I}_{\Psi_\mathrm{S}} > \mathrm{I}_\mathrm{T}\right)$$

$$\quad \mathrm{P}_{R_k} = 0;$$

$$\quad //\ k\ coresponding\ to\ \min\left(\gamma_{R_kD}\right)$$

$$\quad //\text{ignore all previous selections}$$

$$\quad J = J - 1$$

$$\quad recompute\left(\mathrm{I}_{\Psi_\mathrm{S}}\right)$$

$$end\ while$$

$$//\text{Phase 3: SNR Maximization Phase}$$

$$\Gamma_{diff} = \left[\gamma_{SR_{j'}} - \gamma_{R_{j'}D} \mid \gamma_{SR_{j'}} - \gamma_{R_{j'}D} > 0\right]_{j'=1}^{J'}$$

$$//\ j' \in \Psi_\mathrm{S}\ and\ J' \le J$$

$$for\ \left(j' = 1: J'\right)$$

$$\quad while\left(\mathrm{I}_{\Psi_\mathrm{S}} < \mathrm{I}_\mathrm{T}\right)$$

$$\quad\quad \mathrm{P}_{R_l} = \mathrm{P}_{R_l} + \Delta_l;\ //\ l\ coresponding\ \min\left(\Gamma_{diff}\right)$$

$$where, \Delta_l = \mathrm{P} - \mathrm{P}_{R_l}$$

$$//\ ignore\ all\ previous\ selections$$

$$\quad //\Delta_l is\ fed\ while\ satisfying\ \mathrm{I}_\mathrm{T}$$

$$\quad update\ \gamma_{R_{j'}D}\ using\ corresponding\ \mathrm{P}_{R_l}$$

$$\quad end\ while$$

$$end\ for$$

$$\gamma_D = \sum_{j\in\Psi_\mathrm{S}} \gamma_j = \sum_{j\in\Psi_\mathrm{S}} \frac{\gamma_{SR_j}\gamma_{R_jD}}{1 + \gamma_{SR_j} + \gamma_{R_jD}} \qquad \forall j \in \Psi_\mathrm{S}$$

$$\mathrm{P}_\mathrm{T} = \sum_{j\in\Psi_\mathrm{S}} \mathrm{P}_{R_j} \qquad \forall j \in \Psi_\mathrm{S}$$

$$Output: \gamma_D, \Psi_\mathrm{S}, \mathrm{P}_\mathrm{T}, J$$

The Greedy Search based optimization approach of ABC is accomplished by three types of agents after random generation of initial population of candidate solutions where each candidate solution is a food source in bees' language. First, dedicated search agents called Employed Bees (EBs) which are placed one per candidate solution to explore better options in the vicinity, i.e. to carry out local search. Second, selector agents called Onlooker Bees (OBs) selectively update the solutions based on their fitness in the whole population. Roulette wheel stands as one of the most commonly employed fitness calculator. Finally, the replace agents called scout bees (SBs) perform global search to find new replacements of the exhausted solutions.

B. ABC Optimization

The Greedy Search based optimization approach of ABC is accomplished by three types of agents after random generation of initial population of candidate solutions where each candidate solution is a food source in bees' language. First, dedicated search agents called Employed Bees (EBs) which are placed one per candidate solution to explore better options in the vicinity, i.e. to carry out local search. Second, selector agents called Onlooker Bees (OBs) selectively update the solutions based on their fitness in the whole population. Roulette wheel stands as one of the most commonly employed fitness calculator. Finally, the replace agents called scout bees (SBs) perform global search to find new replacements of the exhausted solutions. The pseudo code for ABC's optimization is provided below with tasks performed by its agents corresponding to our proposed algorithm.

$$initialize\ M\ candidate\ solutions$$

$$for^1\ C = 1: iterations$$

$$//\text{Level 1: Employed Bees (EBs) - Full Enhancement}$$

$$\quad for^2\ m = 1, 2, \cdots, M$$

$$\quad\quad randomly\ generate\ integer\ \delta, s.t.\ \delta \ne m$$

$$\quad\quad \left[P_{emp}\right]_i^m = P_i^m + \phi_i^m * \left(P_i^m - P_i^\delta\right); \qquad \forall i$$

$$\quad\quad 0 \le \phi_i^m \le 1$$

$$\quad\quad where,\ \left[P_{emp}\right]_i^m\ is\ i^{th}\ member\ .of\ m^{th}\ solution$$

$$\quad\quad apply\ proposed\ algorithm\ on\ \left[P_{emp}\right]_i^m$$

$$\quad\quad \left[\gamma_D\right]_{new}^m = \sum_{j\in\Psi_F}\left[\gamma_i\right]_{new}^m = \sum_{j\in\Psi_F} \frac{\gamma_{SR_j}\left[\gamma_{R_jD}\right]_{new}^m}{1 + \gamma_{SR_j} + \left[\gamma_{R_jD}\right]_{new}^m};$$

$$\quad\quad replace\ \gamma_D^m\ if\ \left[\gamma_D\right]_{new}^m > \gamma_D^m$$

$$\quad\quad //\ Greedy\ Search$$

$$\quad end\ for^2$$

$$//\text{Level 2: Onlooker Bees (OBs) - Selective Enhancement}$$

$$p^m = \frac{\gamma_D^m}{\sum_{m=1}^{M}\gamma_D^m}; \qquad 1 \le m \le M$$

$for^3\ m = 1,2,\cdots,M \quad //check\ \ fitness\ \ of\ \ solutions$

$Apply\ \ Roulette\ \ Wheel\ \ for\ \ selective\ \ enhancement$

$end\ \ for^3$

$//\text{Level 3: Scout Bees(SBs) - Replacers}$

$if\ \ (rem(C,2) = = 0)$

$\quad for^4\ m = 1,2,\cdots,M$

$\qquad \text{Re}\,generate\ \ exhausted\ \ solutions$

$\quad end\ \ for^4$

$end\ \ if$

$end\ \ for^1$

IV. Simulation Results

We define the following parameters for our system model and for ABC optimization s given in Table I below.

In Fig. 2, we set the stopping criteria for ABC to be 100 iterations, however, ABC proved its quick convergence by achieving the best solutions for both cases in less than 30 iterations. We truncated the graph at 50 iterations for better illustration. The fast convergence is another winning characteristic of ABC to be a preferred choice for solving multi-constrained optimization problems, as it involves less computational time and resources.

TABLE I: PARAMETER SETTINGS

Parameters	*Values*
System Parameters	
N_0	1
P_S, P	$10dB$
ABC Parameters	
M	20
iterations	100

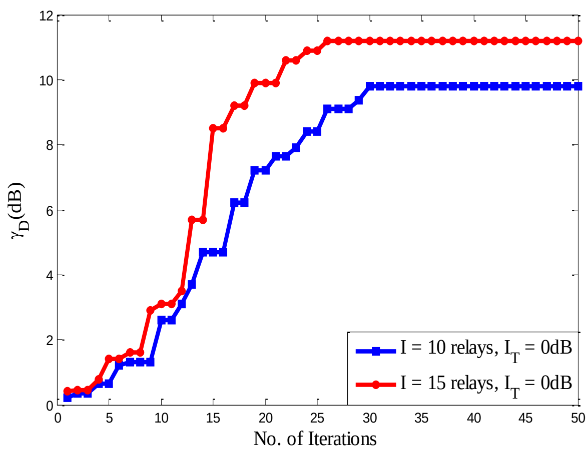

Fig. 2. Convergence behavior of ABC

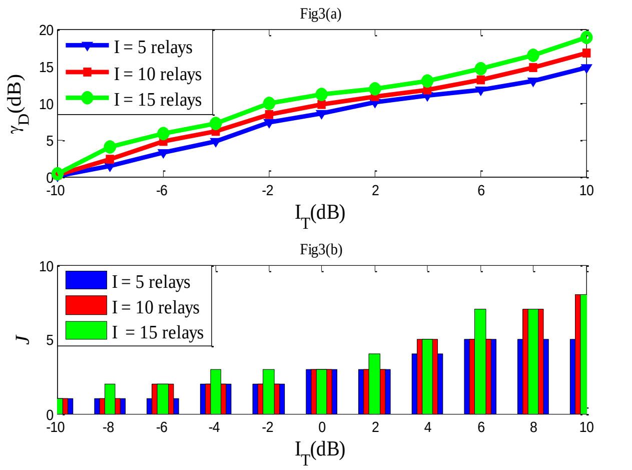

Fig. 3. (a) γ_D vs I_T against different sizes of potential relay network, (b) corresponding number of selected relays

Fig. 3 illustrates the performance in terms of γ_D achieved by the proposed multiple relay selection algorithm. We define I_T over a broad range given by $-10dB \le I_T \le 10dB$. As shown in Fig. 3(a), it is an expected behavior of γ_D to rise when I_T is relaxed. However, in addition to a relaxed interference upper-limit, γ_D is also enhanced by increasing the size of relay network, since it gives more choices to pick the best possible combination of relays. This result is supported by Fig. 3(b) also which shows the corresponding number of selected relays. At certain points, i.e. $I_T = \{-10dB, 0dB\}$, the algorithm selects equal number of relays for all available sets, however, the greater the number of available relays, the more enhanced is the achieved SNR. Second, if I_T is made too tight, i.e. $I_T = -10dB$, multiple relay selection takes the form of single best relay selection. If I_T is further reduced, secondary communication will cease. On the opposite end, we move towards achieving full cooperative diversity.

In Fig. 4, we do not perform relay selection and force all relays to forward source's message under same constraints. For this purpose, first we applied transmit power saving phase in the same way as proposed multiple relay selection. After that, rather than performing relay selection, we set the precedence of the relays based on $\lambda = \frac{f_{R_iD}}{f_{R_iQ}}$. The lower the λ, the more suppressed is the transmit power for that relay. This power suppression has a clear negative impact on γ_D for low ranges of I_T.

Finally, Fig. 5 depicts the total power transmitted by the relay network. As in the relay selection phase, we deselect the relays which offer low SNR at their corresponding relay-destination link, this criterion automatically gives priority to the relays with high channel gains, which in turn makes them capable to contribute significantly towards γ_D . This feature is further enhanced by increasing the number of potential relays due to better choices available.

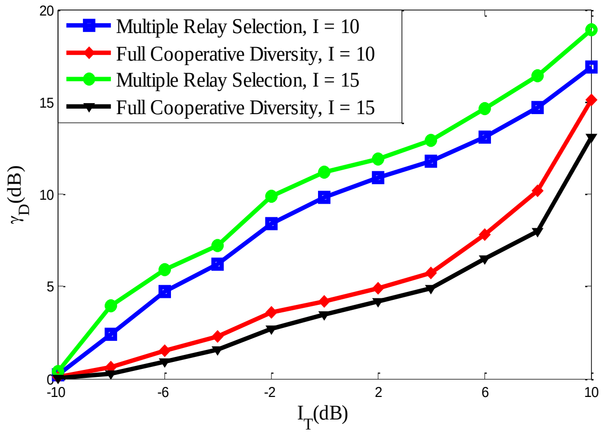

Fig. 4. Multiple relay selection vs all relays participation

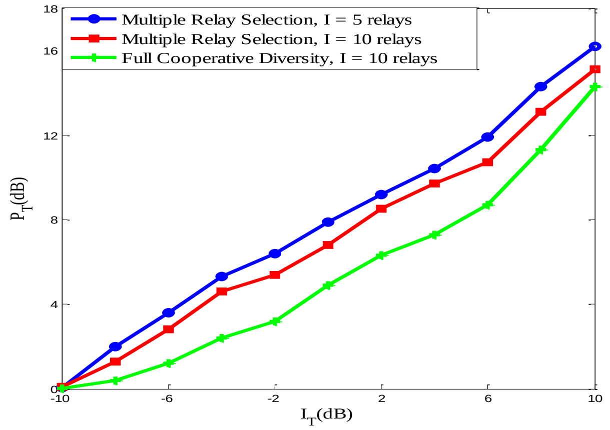

Fig. 5. Total power P_T transmitted at the relay network

V. Conclusions

In this paper, a transmit-power saving scheme incorporated with multiple relay selection for underlay relay-assisted cognitive radio networks is proposed. For this purpose, our decisions are based on the SNR upper bound of end-to-end SNR of each relay-link. Our proposed scheme outsmarts full cooperative diversity in an underlay scenario and achieves high SNR under strict interference and transmit power constraints For optimization, we preferred Artificial Bee Colony due to its ease of implementation, quick convergence and fewer control parameters.

References

[1] I. Krikidis, J. N. Laneman, J. S. Thompson, and S. McLaughlin, "Protocol design and throughput analysis for multi-user cognitive cooperative systems," *IEEE. Trans. Wireless Comm.*, vol. 8, no. 9, pp. 4740-4751, Sept. 2009.

[2] X. Zhang, Z. Yan, Y. Gao, and W. Wang, "On the study of outage Performance for cognitive relay networks (CRNs) with the Nth best-relay selection in Rayleigh-fading channels," *IEEE Wireless Comm. Letters*, vol. 2, no. 1, pp. 110-113, Feb. 2013.

[3] Y. Hu, J. Gross, and A. Schmeink, "Outage probability of multi-relay cognitive relay network with an uncertain number of forwarding relays," in *Proc. IEEE int. Symposium Wireless Comm. Sys.*, Barcelona, Spain, 2014, pp. 350-354.

[4] X. Zhang, Z. Yan, Y. Gao, and W. Wang, "On the study of outage performance for cognitive relay networks (CRN) with the Nth best-relay in Rayleigh-fading channels," *IEEE Wireless Communication Letters*, vol. 2, no. 1, pp. 110-113, Feb. 2013.

[5] M. A. Manna, G. Chen, and J. A. Chambers, "Outage probability analysis of cognitive relay network with four relay selection and end-to-end performance with modified quasi-orthogonal space-time coding," *IET Communication*, vol. 8, no. 2, pp. 233-241, Feb. 2014.

[6] L. Yang, J. Chen, Y. Kuo, and H. Zhang, "Outage performance of DF_based cooperative multicast in spectrum-sharing cognitive relay networks," *IEEE Comm. Letters*, vol. 18, no. 7, pp. 1250-1253, July 2014.

[7] T. T. Duy and H. Y. Kong, "Performance analysis of mixed amplify-and-forward and decode-and-forward protocol in underlay cognitive radio network," *in Proc. China Comm.*, 2016, pp. 115-126.

[8] J. M. Moualeu, W. Hamouda, and F. Takawira, "Performance of AF relay selection with outdated channel estimates in spectrum-sharing systems," *IEEE Comm. Letters*, vol. 20, no. 9, pp. 1844-1847, Sept. 2016.

[9] T. T. Duy and H. Y. Kong, "Exact outage probability of cognitive two-way relaying scheme with opportunistic relay selection under interference constraint," *IET Communications*, vol. 6, no. 16, pp. 2750-2759, Nov. 2012.

[10] B. Zhong, Z. Zhang, X. Zhang. J. Wang, and K. Long, "Partial relay selection with fixed-gain relays and outdated CSI in underlay cognitive networks," *IEEE Trans. Vehicular Tech.*, vol. 62, no. 9, pp. 4696-4701, June 2013.

[11] X. Wang, Y. Sun, H. Yu, T. Feng, *et al*., "Outage performance analysis of amplify-and forward cognitive relay networks with partial relay selection," in *Proc. IEEE Int. Conf. Wireless Comm. Signal Processing*, 2015, pp. 1-5.

[12] Y. H. Ezzeldin, A. Sultan, and M. Youssef, "Best relay selection for underlay cognitive radio systems with collision probability minimization," in *Proc. IEEE Int. Conf. Computing, Networking and Comm.*, 2014, pp. 945-949.

[13] J. M. Moualeu, W. Hamouda, and F. Takawira, "Partial variable-gain AF relay selection with outdated channel estimates in spectrum-sharing networks," in *Proc. IEEE Vehicular Tech. Conf.*, Montreal, QC, Canada, 2016, pp. 1-5.

[14] D. Li, "Outage probability of cognitive radio networks with relay selection," *IET Communications*, vol. 5, no. 18, pp. 2730-2735, Dec. 2011.

[15] J. Xu, H. Zhang, D. Yuan, Q. Jin, and C. X. Wang, "Novel multiple relay selection schemes in two-hop cognitive relay networks," in *Proc. IEEE Int. Conf. Comm. and Mobile Computing*, Qingdao, China, 2011, pp. 307-310.

[16] A. M. ElShaarany, M. M. Abdallah. M. M. Khairy, and K. Qaraqe, "Reduced outage probability relay selection for underlay cognitive networks," in *Proc. IEEE Int. Wireless. Comm. Mobile Computing Conf.*, Nicosia, Cyprus, 2014, pp. 429-434.

[17] A. Ponsich, A. L. Jaimes, and C. A. C. Coello, "A survey of multiobjective evolutionary algorithms for the solution of the portfolio optimization problem and other finance and economics applications," *IEEE Trans. Evolutionary computation*, vol. 17, no. 3, pp. 321-344, June 2013.

[18] D. J. Mala, V. Mohan, and M. Kamalapriya, "Automated software test optimization framework-an artificial bee colony optimization-based approach," *IET Software*, vol. 4, no. 5, pp. 334-348, Sept. 2010.

[19] L. D. S. Coelho and P. Alotto, "Gaussian artificial bee colony algorithm approach applied to loney's solenoid benchmark problem," *IEEE Trans. Magnetics*, vol. 47, no. 5, pp. 1326-1329, May 2011.

[20] L. huang and J. Ai, "Automatic software fault localization based on artificla bee colony," *J. Systems, Engineering and Electronics*, vol. 26, no. 6, pp. 1325-1332, Dec. 2015.

[21] Y. Wang, W. Chen, and C. Tellambura, "A PAPR reduction method based on artificial been colony algorithm for OFDM signals," *IEEE Trans. Wireless Comm.*, vol. 9, np. 10, pp. 2994-2999, Aug. 2010.

[22] M. Zaheer, M. Uzma, A. Asif, and I. M. Qureshi, "Interference control in cognitive radio using joint beamforming and power optimization by applying Artificial Bee Colony," in *Proc. IEEE Int. Multitopic Conf.*, ISB, PAK, 2016, pp. 1-6.

[23] A. Ghasemi, M. A. Masnadi-Sherazi, M. Biguesh, and F. Qassemi, "Channel assignment based on bee algorithms in multi-hop cognitive radio networks," *IET Communications.*, vol. 8, no. 13, pp. 2356-2365, June 2014

[24] M. Li, Y. Hei, and Z. Qiu, "Optimization of non-convex cooperative spectrum sensing with modified artificial Bee Colony algorithm," in *Proc. IEEE Int. Conf. on Computer and Information Tech.*, Xi'an, China, 2014, pp. 70-75.

[25] K. Sultan, I. M. Qureshi, and M. Zubair, "SNR maximization through relay selection and power allocation for non-regenerative cognitive radio networks," in *Proc. IEEE Int. Multitopic Conf.*, ISB, PAK., 2012, pp. 361-364.

[26] J. Wang, X. Li, and K. Ma, "Multiple relay selection scheme based on artificial bee colony algorithm," in *Proc. Int. Conf. Ins., Measurement, Computer., Commun. and Control*, 2013, pp. 1055-1059.

[27] Z. Guowei, L. Peng, S. Fenggnag, and H. Jialin, "Work in progress: Adpative power allocation and relay selection for two hop AF cognitive relay network," in *Proc. IEEE int. Conf. Comm. Net.*, Maoming, China, 2014, pp. 568-571.

[28] T. Xu, J. Ge, and H. Ding, "An efficient distributed link selection scheme for AF-based cognitive selection relaying networks," *IEEE Comm. Letters*, vol. 18, no. 2, pp. 253-256, Jan. 2014.

[29] G. Amarasuriya, M. Ardakani, and C. Tellambura, "Output-threshold multiple-relay-selection scheme for cooperative wireless networks," *IEEE Trans. Vehicular Tech.*, vol. 59, no. 6, pp. 3091-3097, April 2010.

Kiran Sultan is currently associated with Department of Computer and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia. She did her PhD from Air University, Islamabad, Pakistan in 2013 with major research area Signal Processing in Relay-assisted Cognitive Radio Networks. Previously, she did her Masters and Bachelors from UET Taxila in 2008 and 2003 respectively. Her research interests include Cognitive Radio Networks, Cooperative Communication, Detection and Estimation, Evolutionary Algorithms, Soft Computing and Internet of Things.

Atta-ur-Rahman is currently working at Department of Computer Science, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam, KSA as Assistant Professor. Before that he was Associate Professor and Deputy Director at BIIT (Pakistan) where he served for 11 years. He completed his BS degree in Computer Science from University of The Punjab, Lahore, Pakistan; MS degree in EE from International Islamic University, Islamabad, Pakistan and PhD degree in Electronic Engineering from ISRA University, Islamabad, Pakistan in 2004, 2008 and 2012, respectively. His research interests include Digital Signal Processing, Information and Coding theory, Digital Image Watermarking, Wireless/Digital communication, AI and Soft/Evolutionary Computing.

Bassam A. Zafar received his BS in Electronic Engineering and Communication, MSc in Information Technology and PhD in Computer Science (Software Engineering) from De Montfort University, Leicester, UK, in 2003, 2004 and 2008 respectively. He is currently working as an Associate Professor at the Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia. Chairman of Computer & Information Technology Department (Community College). General Supervisor of the Labs & Technical Affairs. Member of Information Systems Department of College of Computing and Information Technology at King Abdulaziz University. His research interests are: Communication, Web-services & System Modelling, Artificial Intelligent Cloud Computing, IoT.

Nahier Aldhafferi is holding BS, MS and PhD in Information Technology from New England University, Australia. He is currently working as Assistant professor as well as Vice Dean of Academic Affairs at department of Computer Information System, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam, KSA. His research interests are Social Media and Privacy, Data Mining, Security and Intelligent Systems.

Abdullah Alqahtani is holding BS, MS and PhD in computer science and information system. He is currently working as Assistant professor as well as Vice Dean for Postgraduate Studies and Scientific Research at department of Computer Information System, College of Computer Science and Information Technology, Imam Abdulrahman Bin Faisal University, Dammam, KSA. His main research interests include Privacy, Decision Support Systems, E-Services, E-Business, E-Government, Database Design and Development, System Modeling, Web-based Information Systems, Intelligent Decision Support Systems, Data Mining; Business Intelligence and System Evaluation.