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Abstract

In wireless communication systems the demand for spectrum resources are increasing rapidly due to increasing spectrum utilization that causes scarceness of the spectrum frequency bands, the Cognitive Radio Network is considered the best solution for this problem, and its cooperated network if it merges with Relay technology. The resource allocation for an OFDM (orthogonal frequency-division multiplexing) with N subcarrier-based-cognitive AF (amplify and forward) for relay network and relay selection is proposed in this paper, the Objective Function is to Maximization the sum transmission rate over the sub-carriers of the secondary user under the Interference constraints from the secondary users (SUs) to the primary users (PUs) and the power constraints for both (the secondary users and relays). The subcarrier allocation and power allocation for the secondary network with relay selection were solved by using a Genetic algorithm.

Keywords: *Cognitive Relay Network, OFDM Technique, Genetic Algorithm, Subcarrier Pairing, Power Allocation, Relay Selection*

INTRODUCTION

The purpose of using the Cognitive Radio technique is to share the licensed spectrum between the legal users called the licensed users (primary users) and the unlicensed users, secondary users). To use the spectrum efficiently due to the increasing demands of wireless devices and the service requirements, and Relay technology is merging with the Cognitive radio technique to enhance the spectrum efficiency and minimize the transmission power for secondary users to avoid interference with the primary users. In the related works the uplink or up/downlink is proposed, with or without resource allocation for the secondary network, with or without relay selection under the interference constraints with the primary users must be under threshold level. In [1] investigated (secondary and primary) networks are used the same frequency band with direct uplink and using one-way AF relay uplink (with two-phases), and adopt OFDM technology with two resources allocation problems to maximize the total sum rate of secondary network under power constraints level, the first problem is power allocation used the Lagragian-method to solve it, and the second is sub-carrier pairing allocation used the linear dual-function to solve this problem, the authors in [2] proposed a Heterogeneous OFDM Cognitive Network to merge a different wireless networks and to sharing the spectrum owned by macro cell with another small cells to improve the spectrum utilization between the licensed and unlicensed cells, the subcarrier allocation, power allocation and relay selection are the resources allocation problem under interference and power threshold are solved by Genetic Algorithm for a small cell that assisted by two - way relay nodes, and to solve cross tier interference between a different cell. A downlink of OFDM cognitive with AF relay network was proposed in [3] to calculate the power allocation (PA) for each subcarrier that is allocated for secondary users and relay nodes to transfer data from sender to destination and then calculate the SINR for each subcarrier arrived to destination this is a formulated optimization problem and used the numerical analysis to calculate the objective function that is to achieve the spectral efficiency under interference temperature.

In [4] without cognitive technique, the AF relay technology is proposed to help the sender and destination to communicate with each other in two-way mode to maximize the total transmission rate with joint resources: power allocation solved by dual function and subcarrier pairing allocation solved by Hungarian method with OFDM spectrum sharing and AO used for primal optimization problem of joint resources allocation. The study in [5] suggested a cognitive amplify and forward (AF two-way) relay technology to share the OFDM spectrum between licensed and unlicensed users, the optimization problem is to maximize the total rate for a secondary (unlicensed) network with joint resources: power allocation, subcarrier allocation and relay selection are solved by GA with all calculations for the: power and interference constraints. Without relay technology, the subcarrier and power allocation are the formulation problems in [6] to maximize the transmission rate for the secondary cognitive uplink OFDM radio network these problems are solved by the uplink- price- power- allocation UPPA algorithm. The cognitive (two-way underlay relay) network with two optimization problems: power allocation and time allocation for transmission frames are investigated in [7] to maximize: the minimum transmission rate for the secondary (unlicensed) network under the power constraints, all problems are solved by sub-optimal algorithm and JPCRA scheme to calculate the power splitting at the relay nodes.

The OFDM cognitive network with uplink DF relay is proposed in [8] to select a set of relay nodes with minimum path loss, to increase the SINR then increase the total capacity. In [9] joint (power, subcarrier) allocation and path selection are the formulation problems for cognitive uplink DF relay for maximizing the total transmission rate for a secondary (unlicensed) network under a power budget and interference threshold the Lagrange method proposed to solve the formulation problems. Non-cooperative network, the uplink cognitive radio network is proposed in [10] with TDMA to maximize the lifetime of the network, the energy allocation is a resource allocation under the energy constraints the GA is proposed to solve this optimization problem. Table (1) illustrates the comparison of the different previous works.

In this research, a (perfect spectrum sensing) is proposed for uplink cognitive uplink (one-way) AF relay network to maximize the total transmission rate, with combined resources allocation and relay selection using the genetic algorithm under the interference and power constraints, the purpose to proposed these constraints are for avoiding the interference by the primary users and proposed the both primary users and secondary network are using the OFDM modulation technique.

Table (1): Comparison of Different Previous Works

Ref.	**Year**	**Cognitive Radio**	**Relay Protocol**	**Up/Down Link**	**Resources Allocation**	**Objective Function**	**Multiplexing**	**Optimization Technique**
1	2020	√	DF	Up link	Joint Power/ subcarrier allocation	Maximization transmission Rate	OFDM	Lagragian and Dual method
2	2020	√	DF	Two-way	Joint Power/ subcarrier allocation and relay selection	Maximization transmission Rate	OFDM	GA
3	2021	√	AF	Downlink	Calculate the power for each subcarrier	Achieve Spectral Efficiency	OFDM	Numerical Analysis
4	2022	—	AF	Two-way	Joint Power/ subcarrier allocation	Maximization Transmission Rate	OFDM	Dual+Hungarian method and AO
5	2022	√	AF	Two-way	Joint Power/ subcarrier allocation and relay selection	Maximization Transmission Rate	OFDM	GA
6	2023	√	—	Up link	Joint Power/ subcarrier allocation	Maximization Transmission Rate	OFDM	UPPA
7	2023	√	DF	Two-way	Joint Power/ subcarrier allocation	Maximization Transmission Rate	—	JPCRA, Sub-optimal Algorithm
8	2024	√	DF	Up link	Best relay type selection	Achievable Rate	—	Numerical Analysis
9	2024	√	DF	Up link	Joint Power/ subcarrier allocation	Maximization Transmission Rate	—	Lagragian method
10	2024	√	—	Up link	Energy allocation	Maximization lifetime	TDMA	GA
This Paper		√	AF	Up link (One-Way)	Joint Power/ subcarrier allocation and relay selection	Maximization transmission Rate	OFDM	GA

Problem Statement

The problem formulation that proposed in this research paper to maximize the total capacity for secondary network are:

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- Subcarrier allocation for the secondary users and relay nodes.
- Power allocation for the secondary users and relay nodes.
- Relay selection, to select the best relay that help to maximize the total capacity

All of these problems are solved under the power threshold and interference constraints.

1. The important challenges proposed for Cognitive Relay Networks are the resources allocation RA (power allocation and sub-carrier allocation), interference management and relay selection with consideration of all constraints to prevent harmful the primary user.

2. The optimization problem for RA and relay selection has been proposed for Orthogonal Frequency Division Multiplexing OFDM based on cognitive (one-way) underlay relay network with secondary users (one pair) to enhance the spectrum efficiency.

System Models

In this research paper: an OFDM technique-based uplink for Cognitive (AF one-way Relay) Networks is investigated, the system model shown in Figure (1) contains: one (primary user pair, sender and destination), one secondary user pair (sender and destination), and multiple relays (K) to assist the secondary user to communicate with destination user, in this model the number of relays is proposed two relays (K=2). Table (2) provides system parameter definitions.

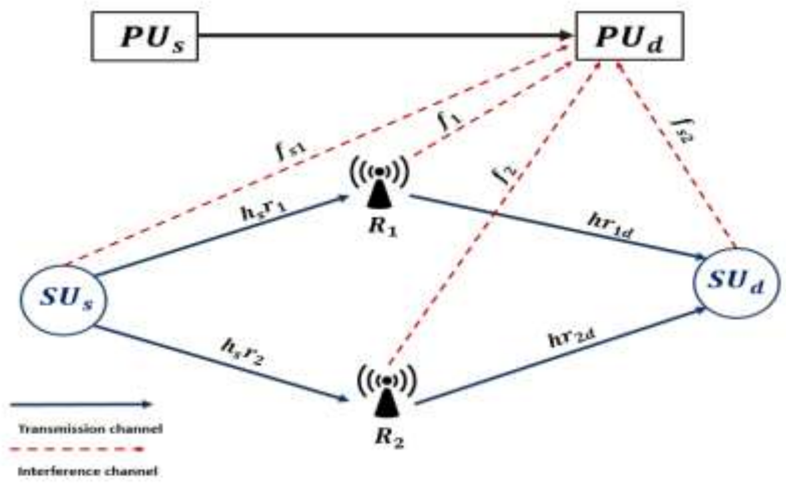

Figure 1: System Model

Table 2: System Model Definitions

K	Number of relays {1, …., *k* , …, K}
N	The overall Bandwidth is divided into: N sub-carrier.
Np	The number of sub-carrier utilized by Primary (lisences) user Np∊N Np = {1,…, *l* ,…, L}
Ns	Number of sub-carriers utilized by Secondary (unlicensed) network Ns∊N Ns = {1,…, *m* ,…, M}
i	Sub-carrier for phase**I** from (SU-s) to Relay nodes. *i*∊Ns
j	Sub-carrier for phase**II** from relay nodes to (SU-d). *j*∊Ns
A	2D matrix that describe a location of <*i* , *j*> pairs, A=1 if <*i* for phase**I**> & <*j* for phase**II**>
B	3D matrix to describe the subcarrier pairs assignment to *k* relays.
x_{si}^{k}	Represent the symbols that transmitted by SU-s on sub-carrier *i*.
p_{si}^{k}	The transmit power of SU-s to the *k*-relay on sub-carrier *i*.
h_{si}^{k}, hr_{j}^{k}	The channel gain from SU-s to the *k* relay on sub-carrier *i*, the channel gain from *k* relay to the SU-d on sub-carrier *j*.
p_{Rj}^{k}	Transmit power of *k* relay on sub-carrier *j*.
f_{si}^{l}	Interference channel from SU-s on sub-carrier *i* to PU on sub-carrier *l*.
f_{Rj}^{kl}	Interference channel from the *k* relay on sub-carrier *j* to PU on sub-carrier *l*.

Secondary Network Analysis

To analysis the secondary (unlicensed) network with the uplink AF one-way relay in two-phases to exchanging the signals among the secondary users [11], [12], and [13].

1. Phase **I**: the SU-s transmits a signal to the selected *k*- relay in the allocated sub-carrier (*i*) the received signal in the *k*-relay is:

$$y_i^k = \sqrt{p_{si}^k} h_{si}^k x_{si}^k + \theta_i^k \qquad (1)$$

θ_i^k : is the additive white Gaussian noise symbols as (AWGN) for radio frequency channels.

2. Phase **II**: then the selected relay amplifies the receiving signal from SU-s with the amplification factor M_j^k and forwards the signals on the sub-carrier *j* to SU-d.

$$p_j^k = \left(y_i^k . M_j^k\right)^2 + \sigma^2 \qquad (2)$$

$$M_j^k = 1/\sqrt{{y_i^k}^2 + \sigma^2} = 1/\sqrt{p_{si}^k {h_{si}^k}^2 + \sigma^2} \qquad (3)$$

The signal received in SU-d can be calculated in equation (4):

$$y_j^k = M_j^k \sqrt{p_{Rj}^k} h_j^k y_i^k + \theta_j^k \qquad (4)$$

The transmission rate of SU-d assisting by the relays of two-way on sub-carrier <*i,j*> is:

$$R_{AF}^{i,j,k} = \frac{1}{2}\log_2\left(1 + SNR_i^{SR}\right) + \frac{1}{2}\log_2\left(1 + SNR_j^{RD}\right) \qquad (5)$$

Where, SNR_i^{SR}, SNR_j^{RD} are the signal to noise ratio of phase**I** and phase**II** respectively.

Interference Model

The interference model can be calculated in this study to avoid any interference signal from the (SU-s when transmits data on subcarrier *i* to k-relay and then the relays amplify and forward it to the SU-d on subcarrier *j*) that effects on primary (licensed) users.

The interference signal from SU-s to PU-d on subcarrier *i* is:

$$I_1^i = \sum_{i\in Ns} \sum_{k\in K} \left(p_{si}^k \sum_{l\in Np} {f_{si}^l}^2\right) \le I_{Th} \qquad (6)$$

The interference signal from relay to the PU-d on sub-carrier j is:

$$I_2^j = \sum_{j\in Ns} \sum_{k\in K} \left(p_{Rj}^k \sum_{l\in Np} {f_{Rj}^{kl}}^2\right) \le I_{Th} \qquad (7)$$

I_{Th} : is a threshold known by PU.

Objective Function (Problem Statement)

The objective function in this research paper is to maximization the total transmission rate with (subcarrier allocation, power allocation, and the relay selection) for uplink model into two phases to complete the communication between SU-s and SU-d, under the power and interference with PU-d constraints.

The constraints to solving the objective function

OP: $\begin{pmatrix}\max \\ \text{A,B,P}\end{pmatrix} \quad \sum_{i\in Ns} \sum_{j\in Ns} \sum_{k\in K} B_{i,j}^k A_{i,j}$

C1: $\sum_{i,j\in Ns} A = 1 \ , \ \sum_{k\in K} B = 1$

C2: $\sum_{i\in Ns} \sum_{k\in K} p_{(s)i}^k \le P_s^{max}$

C3: $\sum_{j\in Ns} p_{Rj}^k \le P_{Rk}^{max} \quad for\ all\ k$

C4: $I_1^i = \sum_{i\in Ns} \sum_{k\in K} \left(p_{si}^k \sum_{l\in Np} {f_{1i}^l}^2\right) \le I_{th}$

C5: $I_2^j = \sum_{j\in Ns} \sum_{k\in K} \left(p_{Rj}^k \sum_{l\in Np} {f_{Rj}^{kl}}^2\right) \le I_{th}$

Executed Model

In this study the Genetic algorithm is proposed to solve three activities for resources allocation problems: (subcarrier allocation, power allocation, and best relay selection) for maximizing the overall transmission rate for a secondary (unlicensed) network, in this model we assume one primary user pair, one secondary user pair, and two AF relays (k=2), the total subcarrier (N=6). Two subcarriers allocated to the primary user (Np=2) the unoccupied subcarrier allocated to secondary network (Ns=4).

RESULTS

The optimization results using Genetic Algorithm shown in fig. (2), with number of variables (40) from variable (25) to variable (40) represented the all power allocations. 10 iterations, each iteration have number of population size equal to (500), the population ranges (0:255) levels, the maximum power constraint for all users and relay equal to 1.5 watt and assumed the interference threshold I_{th}=1e-9.

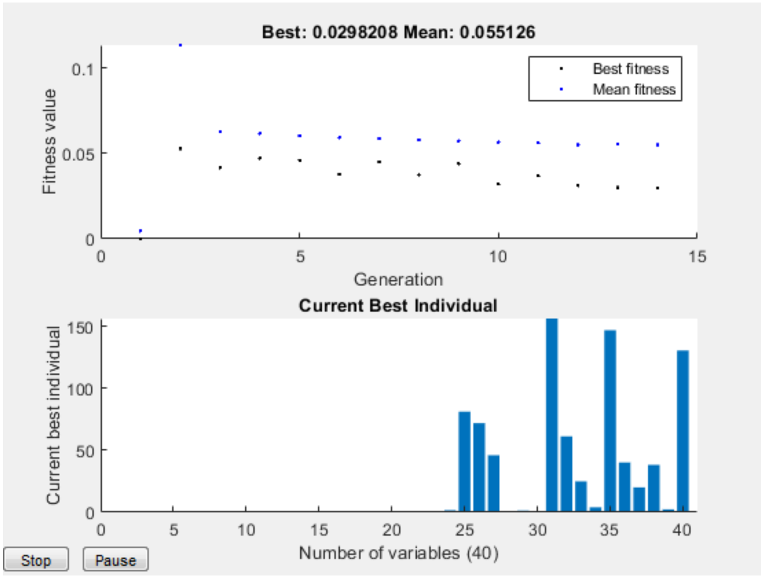

Figure 2: The Best Results (Best Maximum Rate) of Genetic Algorithm

The best subcarrier allocation matrix (A), and relay assignment each relay has matrix are B1, B2 respectively:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$B1 = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \end{bmatrix} \quad , \quad B2 = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 \end{bmatrix}$$

In matrix (A) the rows represent subcarrier i (phaseI when SU-s transmit to relays), the columns represent subcarrier j (phaseII while relays forward signal to SU-d). The row1 in matrix A equal to (1) when the i=1 paired with j=1 ➔ <1,1> pair that mean phaseI on subcarrier 1, phaseII on subcarrier 1, and so on. To find the subcarrier pair <i,j> assignment to relay1 and relay2 by multiply matrix A with matrix B1 and B2 respectively, get the <1,1> and <2,3> pairs are allocated for to relay1. And the <3,4> and <4,2> pairs are allocated to relay2. The subcarrier pairs shown in fig. (3).

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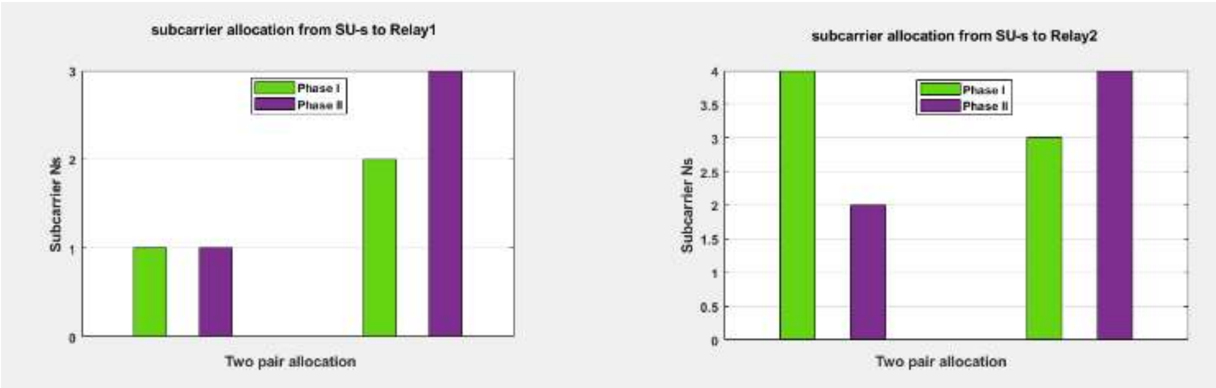

Figure 3: Subcarrier Allocations

The power allocations for SU-s, relays on each subcarrier shown in fig. (4).

The signal to noise ratio SNR can be calculated for each subcarrier pair as shown in figure (5).

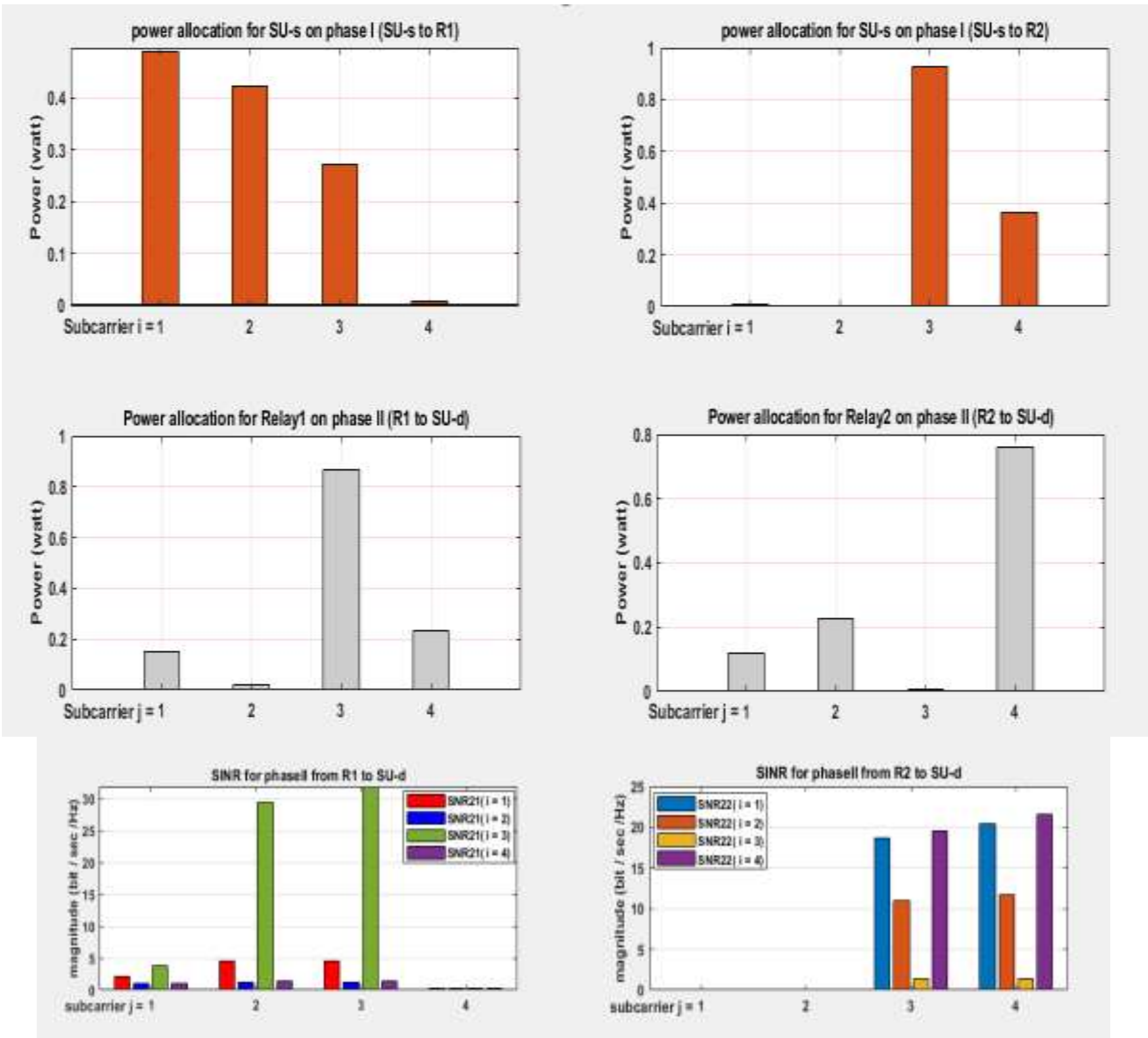

Figure (5): SNR for Each Subcarrier Pairs, Under the Max. Power Constraints ($P_{max.}$=1.5 Watt), And Interference Constraints ($I_{Th}=10^{-9}$).

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In fig. (6) Show the max. transmission rate on all subcarrier for relay1 and relay2. By using Shannon theory we can be calculate the transmission rate:

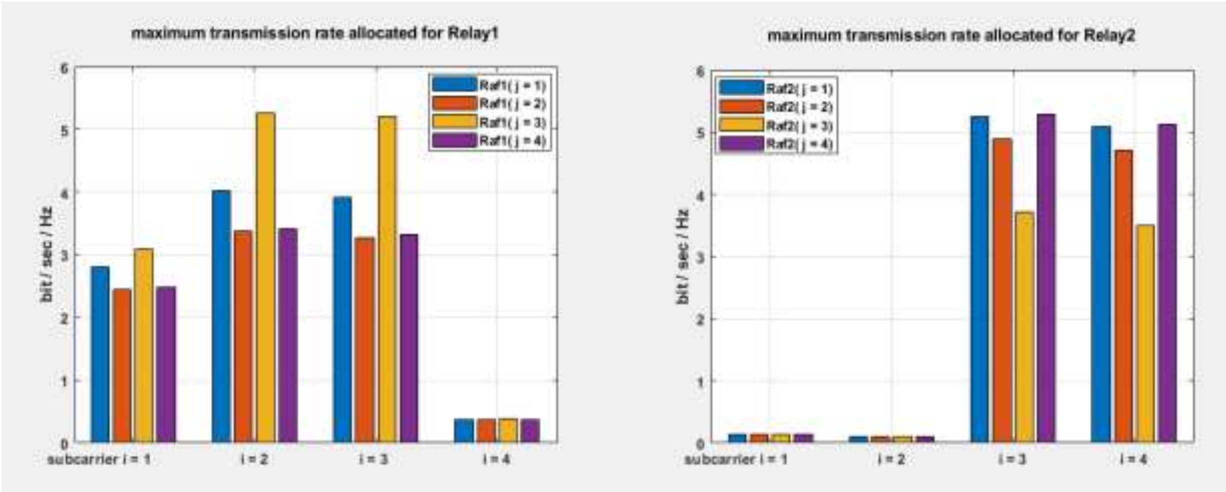

Figure (6): Max. Rate for All Pairs <i,j>, under the Max. Power Constraints ($p_{max.}$=1.5 watt), and Interference Constraints ($I_{Th}=10^{-9}$).

Rate=B $\log_2$ (1+SINR), B is the band width of channel in Hz. The rate of uplink amplify and forward relay1 and relay 2:

$$Raf1=0.5B\log_2(1+SNR11_{(phase\ I)})+0.5B\log_2(1+SNR21_{(phase\ II)}) \quad (8)$$

$$Raf2=0.5B\log_2(1+SNR12_{(phase\ I)})+0.5B\log_2(1+SNR22_{(phase\ II)}) \quad (9)$$

From the results of this model if $I_{Th}=10^{-9}$ the total maximum rate can be calculated as: R_T = R1+R2, R_T = 8.0473+9.9856, the total rate is: R_T = 18.0329 bit/sec/Hz. If the interference threshold will be reduced to $I_{Th}=10^{-12}$ the maximum transmission rate will be increased to: R_T =19.9832 bit/sec/Hz, this results show the Genetic Algorithm enhanced the spectrum usage efficiently with high transmission rate for secondary network.

Conclusion

In this paper the cognitive uplink AF relay network using OFDM as a modulation technique is proposed. The primary user shared the spectrum with the secondary network. The objective function is for maximizing the transmission rate for secondary networks through power allocation, subcarrier allocation, and the best relay selection below interference constraints and power constraints to avoid the interference with the primary user. we proposed a Genetic algorithm as an optimization technique to solve these formulation problems under all the interference constraints that proposed.

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