# Adaptive Bit-Loading in Relay-Aided Cognitive Radio Network

Muhammad Zain Siddiqi*, Haji Muhammad Furqan†, Tayyaba Jabeen‡,
Zain Ali‡ and Guftaar Ahmad Sardar Sidhu‡
* Department of Computer Sciences, Lahore Leads University, Lahore, Pakistan
‡ Department of Electrical Engineering, COMSATS Institute of Information Technology
Islamabad, Pakistan
† School of Engineering and Natural Sciences, Istanbul Medipol University, Istanbul, Turkey
Emails: *Zainsiddiqiciit@gmail.com, ‡guftaarahmad@comsats.edu.pk,
‡tayyabajabeen37@gmail.com , ‡zainalihanan1@gmail.com, †hamadni@st.medipol.edu.tr

***Abstract*—In this work, we consider a joint power allocation and bit loading problem in an orthogonal frequency division multiplexing (OFDM) based cognitive radio (CR) network. The objective is to maximize the end-to-end rate in a relay aided dual hop transmission subject to individual power constraints at each transmission node. More specifically, an underlay CR transmission is considered, where the secondary nodes transmit simultaneously with the primary nodes subject to an interference protection criteria. An efficient algorithm is proposed which maximizes the overall throughput while meeting all the constraints. Simulations results are presented to validate the performance of our proposed scheme.**

## I. INTRODUCTION

The increasing demand of high data rates and rapid congestion in the wireless traffic have made it hard to facilitate the requirements of all the users simultaneously. The cognitive radio (CR) has been introduced as a promising solution to improve the spectral efficiency through efficient use of underutilized spectrum [1] where unlicensed secondary users (SUs) are allowed to get access and use the licensed primary user's (PUs) spectrum either by underlay spectrum access (USA) mode or overlay spectrum access (OSA) mode [2]. Meanwhile, the relay enhanced transmission is being considered to enhance performance of a system where source and destination are located at a larger distance [3]. Furthermore, orthogonal frequency division multiplexing (OFDM) based transmission has been adopted in several wireless system as an effective solution to inter-symbol interference [4].

The performance of an OFDM based system can be improved by proper power allocation and bit loading over different subcarriers [5]. The benefits of adaptive bit loading in OFDM based CR transmission has been realized in [6]- [9]. The work in [6] presented the power and bit loading algorithms to maximize the throughput of a SU subject to interference constraint of PUs. The problem of subcarrier allocation and bit loading in multi-user CR transmission was considered in [7]. In [7], under interference leakage scenario on both ends, an integer programming based solution was proposed to maximize the throughput of CR users while keeping the interference to primary network within acceptable limits. Under imperfect channel conditions, [8] explored bit loading solutions for CR communication subject to bit error rate (BER) constraints. The authors extended the work presented in [9] by designing joint power and bit loading algorithms under total power constraints. The resource allocation in OFDM based relay networks has been studied under amplify and forward (AF) and/or decode and forward (DF) protocols in [10]- [14]. To minimize the overall transmission power in DF relay communication, a bit loading algorithm was designed in [10] under a minimum discrete bit rate requirement. Furthermore, the work in [11] proposed bit and power allocation scheme in AF relay networks to maximize the BER under a sum power constraints over all nodes. The optimization with sum power constraint is not practical, hence, a separate power limit should be considered.

The problem of resource allocation in relay enhanced CR becomes more challenging because a two hop interference protection to primary network is mandatory in this case. The authors in [12] proposed a power allocation strategy in relay based underlay CR network. The objective was to maximize the sum throughput subject to individual power constraint at each transmitting node and an interference constraint for each hop transmission. The work was extended to two-way relay enhanced CR communication in [13], where the power allocation over two transceiver nodes as well as at relay was obtained through a sequential decomposition techniques. More recently, the problem of power allocation in one-way CR relay network with imperfect channel state information (CSI) is considered to maximize the capacity in [14]. The problem of bit loading in relay based CR system has not been considered in the literature to the best of author's knowledge.

978-1-5386-3132-4/17/$31.00 ©2017 IEEE

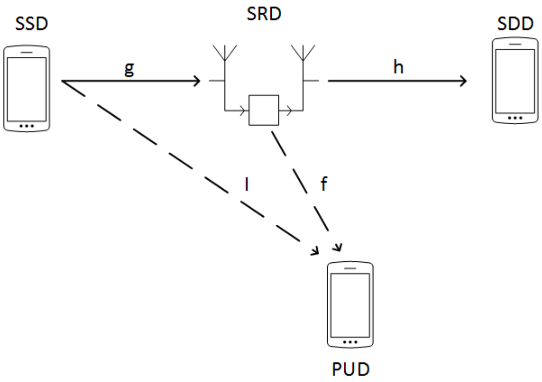

Figure 1. System Model

In this work, we consider an underlay CR transmission, where secondary source node communicates with destination through an AF relay. We maximize the system throughput under individual transmit power constraint of secondary source and relay nodes and an independent interference constraint at each hop. In the first step, the proposed algorithm finds the power optimization over different subcarriers to maximize the sum rate and then the discrete bit loading over each subcarrier is done through an iterative process such that all of the contraints do satisfy.

## II. SYSTEM MODEL AND PROBLEM FORMULATION

### A. System Model

We consider a network where secondary source device (SSD) communicates with the secondary destination device (SDD) with the help of a relaying node called secondary relay device (SRD) as shown in Fig.1. An underlay CR strategy is used where SSD coexist with the primary user device (PUD) and both can exploit the entire spectrum at the same time in such away that the interference generated by SSD is under the tolerance of PUD [2]. An OFDM transmission with total number of N subcarriers is considered where all the nodes are assumed to be equipped with single antenna and operate under half duplex mode. Let the channel gain from SSD-SRD over k-th subcarrier is $g_k$ and from SRD-SDD over the k-th carrier is denoted by $h_k$. Similarly, the gains from SSD-PUD and SRD-PUD over the k-th subcarrier are represented by $l_k$ and $f_k$, respectively. Thus, the signal received over the k-th subcarrier by SRD from SSD represented by $y_k^{SRD}$, can be expressed as;

$$y_k^{SRD} = \sqrt{p_k} g_k x_k + z_k, \tag{1}$$

where, $p_k$ is the power allocated at SSD over the k-th carrier, $z_k$ is the Additive White Gaussian Noise (AWGN) with variance $\sigma_k^2$, and transmitted symbol is denoted as $x_k$.

The received signal over the $k$-th carrier at SDD is;

$$y_k^{SDD} = \sqrt{q_k}\eta_k(g_k h_k \sqrt{p_k} x_k + h_k z_k) + w_k, \tag{2}$$

where, $\eta_k \triangleq \left(\sqrt{p_k|g_k|^2 + \sigma_k^2}\,\right)^{-1}$, $q_k$ is the transmit power allocated to the $k$-th subcarrier of SRD, and $w_k$ represents the AWGN at SDD with the variance $\sigma_k^2$.

At high signal-to-noise ratio (SNR), throughput over k-th subcarrier can be approximated by [12];

$$r_k \approx \frac{1}{2}\log_2\left(1 + \frac{\left(\sqrt{p_k}|g_k|\sqrt{q_k}|h_k|\right)^2}{\sigma_k^2\left(\sqrt{p_k}|g_k|\right)^2 + \sigma_k^2\left(\sqrt{q_k}|h_k|\right)^2}\right), \tag{3}$$

where the factor $\frac{1}{2}$ is due to the two time slots used for a complete transmission.

### B. Problem Formulation

Our main objective is to design an algorithm such that the throughput of secondary users maximizes under the interference constraints of PUD and the individual transmission power budgets at the SSD and SRD. We aim to optimize the discrete bit loading (i.e., $b_k, \forall k$) over $N$ subcarriers as well as the power allocation in an OFDM based underlay system. Mathematically, the optimization problem can be written as,

$$\max_{b_k, p_k, q_k} \quad \sum_{k=1}^{N} b_k, \tag{4}$$

$$\text{s.t.} \quad \sum_{k=1}^{N} b_k \leq \sum_{k=1}^{N} r_k, \tag{5}$$

$$\sum_{k=1}^{N} p_k |l_k|^2 \leq I_{th}, \tag{6}$$

$$\sum_{k=1}^{N} q_k |f_k|^2 \leq I_{th}, \tag{7}$$

$$\sum_{k=1}^{N} p_k \leq P_T, \tag{8}$$

$$\sum_{k=1}^{N} q_k \leq Q_T. \tag{9}$$

Here, $I_{th}$ denotes the maximum allowable interference threshold whereas $P_T$ and $Q_T$ are the total transmission power budget limits at SSD and SRD, respectively. The first two constraints ensure that the interference produced by secondary users should be less than the acceptable interference limit of PUD in order to protect it from harmful interference in first and second phase of transmission, respectively. The equations (8) and (9) present the maximum power constraints at SSD and SRD, respectively.

## III. PROPOSED SOLUTIONS

It can easily be recognized that the problem (4) is a mixed integer optimization problem and is difficult to solve. For the tractability of solution, we adopt a decomposition approach where we first consider per carrier power allocation for an OFDM based relay aided CR network that can be written as,

$$\begin{aligned} \max_{p_k,q_k} \quad & \sum_{k=1}^{N} r_k, \\ \text{s.t.} \quad & \sum_{k=1}^{N} p_k \leq P_T, \qquad \sum_{k=1}^{N} q_k \leq Q_T, \\ & \sum_{k=1}^{N} p_k|l_k|^2 \leq I_{th}, \quad \sum_{k=1}^{N} q_k|f_k|^2 \leq I_{th}. \end{aligned} \tag{10}$$

Without the loss of generality, we efficiently solve the above sub problem to maximize average number of bits arrive at destination. The power is allocated to block of N subcarriers at source and relay node such that;

$$a1_k = \min\left(t1_k, v1_k\right), \qquad \forall k, \tag{11}$$

with $t1_k = \frac{X_T}{N}$ and $v1_k = \frac{I_{th}}{s1_k}$ where,

$$(X_T, s1_k) = \begin{cases} (P_T, \sum_{k=1}^{N}|g_k|^2), & \text{for } a1_k = P_k, \\ (Q_T, \sum_{k=1}^{N}|h_k|^2), & \text{for } a1_k = Q_k. \end{cases}$$

With the obtained interference aware power allocation, we find the throughput at the k-th sub-carrier using expression (3). Next, we map the obtained $r_k$ to the nearest integer value. However, this may disturb the power allocation that is to say that some carriers may require more power while other require less. Thus, a power refinement at source and relay nodes according to the latest value of bits is required. We adopt $F(\hat{b}_k, q_k)$ and $E(\hat{b}_k, p_k)$ for power refinement at source and relay node, respectively, given as,

$$\hat{F}(\hat{b}_k, q_k) = \frac{(2^{\hat{b}_k} - 1)\sigma_k^2 q_k |h_k|^2}{|g_k|^2(q_k|h_k|^2 - (2^{\hat{b}_k} - 1)\sigma_k^2)}, \quad \forall k, \tag{12}$$

$$\hat{E}(\hat{b}_k, p_k) = \frac{(2^{\hat{b}_k} - 1)\sigma_k^2 p_k |g_k|^2}{|h_k|^2(p_k|g_k|^2 - (2^{\hat{b}_k} - 1)\sigma_k^2)}, \quad \forall k, \tag{13}$$

where, $\hat{b}_k$ is the discrete value of data rate. Since the source and relay node's powers are dependent on each other, the resultant powers updated once again. After power refinement, we calculate the sum power at source ($P_s = \sum_{k=1}^{N} \bar{p}_k$), the sum power at relay node ($Q_s = \sum_{k=1}^{N} \bar{q}_k$), interference at any k-th carrier of source ($Ith_{kp} = \bar{p}_k * |l_k|^2$), interference at k-th carrier of relay node ($Ith_{kq} = \bar{q}_k * |f_k|^2$), sum interference at source ($PIth_s = \sum_{k=1}^{N} Ith_{kp}$) and sum interference at relay node ($QIth_s = \sum_{k=1}^{N} Ith_{kq}$) in order to check all the constraints. The calculated parameters are checked against their corresponding constraints in such a way that if all the obtained parameters fulfill their corresponding constraints then **Algorithm2** is followed. In **Algorithm2**, for all N, a sub-carrier having minimum incremental power is selected and a bit is added to it. Again, the desired parameters ($P_s$, $Q_s$, $PIth_s$, and $QIth_s$) are calculated in order to check all the constraints. It should be noted that the while loop in **Algorithm2** terminates at a point where any of the condition violates and we return to **Algorithm1**. Furthermore, in **Algorithm1**, step 7 and 8 show that if any one of the parameter of either source or relay node exceeds to its threshold level then we move to **Algorithm3** or **Algorithm4** according to corresponding conditions. However, if all of the parameters violate their constraints then problem arises that which hop should be selected in order to start decrements in the power. In this case, the hop with maximum total available power compared to the other one is assumed to be selected first to start decreasing the power until all the constraints satisfy (step 9). Step wise description of the proposed scheme is given in **Algorithm1** to **Algorithm4**.

**Algorithm 1** :Proposed Solution

```
1 Allocate power to all N carriers at source and relay node using (11).
2 Compute $b_k$ using expression (3).
3 Round the bits as $\hat{b}_k = \text{round}\ (b_k)$.
4 Update the transmit powers $\hat{p}_k = \hat{F}(\hat{b}_k, q_k)$ and $\hat{q}_k = \hat{E}(\hat{b}_k, p_k)$ corresponding to the quantized value of $\hat{b}_k$, where, $\hat{F}(\hat{b}_k, q_k)$ and $\hat{E}(\hat{b}_k, p_k)$ are obtained using (12) and (13) respectively. Refine $\bar{p}_k = \bar{F}(\hat{b}_k, \hat{q}_k)$ and $\bar{q}_k = \bar{E}(\hat{b}_k, \hat{p}_k)$ again.
5 Set $P_s = \sum_{k=1}^{N} \bar{p}_k$, $Q_s = \sum_{k=1}^{N} \bar{q}_k$, $Ith_k = \bar{p}_k * |l_k|^2$, $Ith_k = \bar{q}_k * |f_k|^2$, $PIth_s = \sum_{k=1}^{N} Ith_{kp}$, and $QIth_s = \sum_{k=1}^{N} Ith_{kq}$ .
6 while ($P_s \leq P_T$ & $PIth_s \leq I_{th}$ & $Q_s \leq Q_T$ & $QIth_s \leq I_{th}$)
      Go to Algorithm 2
  end while
7 while ($P_s \geq P_T$ & $QIth_s \geq I_{th}$ & $Q_s \leq Q_T$ & $QIth_s \leq I_{th}$)
      Go to Algorithm 3
  end while
8 while ($P_s \leq P_T$ & $PIth_s \leq I_{th}$ & $Q_s \geq Q_T$ & $QIth_s \geq I_{th}$)
      Go to Algorithm 4
  end while
9 while ($P_s \geq P_T$ & $PIth_s \geq I_{th}$ & $Q_s \geq Q_T$ & $QIth_s \geq I_{th}$)
      if ($Q_s < P_s$)
          Repeat steps I to IV of Algorithm 3.
      else
          Repeat steps I to IV of Algorithm 4.
      end if
  end while
```

### A. *Suboptimal Algorithm*

To reduce the computational complexity of the proposed scheme in previous section we propose a suboptimal approach which compromises little on the performance. Initially, power allocation, throughput calculation, and bits are rounded in the same way as discussed in previous proposed algorithm. For bit loading a bit is added to the first sub-carrier of all N carri-

**Algorithm 2**

```
if ($P_s < Q_s$)
   I. Find $c_k = \bar{F}(\hat{b}_k+1,\bar{q}_k) - \bar{F}(\hat{b}_k,\bar{q}_k) \quad \forall k$.
   II. Obtain $k^* = \arg\ \min_k\ c_k$.
   III. Update $\hat{b}_{k^*} = \hat{b}_{k^*}+1$.
   IV. Refine $\bar{p}_k = \bar{F}(\hat{b}_{k^*},\bar{q}_{k^*})$ , $\bar{q}_k = \bar{E}(\hat{b}_{k^*},\bar{F}(\hat{b}_{k^*},\bar{q}_{k^*}))$.
   V. Calculate $P_s$, $Q_s$, $PIth_s$, and $QIth_s$.
else
   VI. Find $c_k = \bar{E}(\hat{b}_k+1,\bar{p}_k) - \bar{E}(\hat{b}_k,\bar{p}_k) \quad \forall k$.
   VII. Repeat step II and III.
   VIII. Refine $\bar{q}_k = \bar{E}(\hat{b}_{k^*},\bar{p}_{k^*})$ , $\bar{p}_k = \bar{F}(\hat{b}_{k^*},\bar{E}(\hat{b}_{k^*},\bar{p}_{k^*}))$.
   IX. Calculate $Q_s$, $P_s$, $QIth_s$, and $PIth_s$.
end if
```

**Algorithm 3**

```
if ($P_s > Q_s$)
   I. Find $c_k$= $\bar{F}(\hat{b}_k-1,\bar{q}_k) - \bar{F}(\hat{b}_k,\bar{q}_k) \quad \forall k$.
   II. Get $k^* = \arg\ \min_k\ c_k$.
   III. Update $\hat{b}_{k^*} = \hat{b}_{k^*}-1$.
   IV. Repeat steps IV and V of Algorithm 2.
else
   V. Repeat steps VI to IX of Algorithm 2.
end if
```

ers. After that parameters i.e., $P_s$, $Q_s$, $PIth_s$, and $QIth_s$ are calculated in order to check all the constraints. For $P_s \le P_T$ & $PIth_s \le I_{th}$ & $Q_s \le Q_T$ & $QIth_s \le I_{th}$, if $P_s < Q_s$ & $PIth_s < QIth_s$, add a bit to first carrier of all N carriers in such a way that $\bar{b}_{k^*} = \bar{b}_k + 1$. Refine the powers according to the updated rate and check all the constraints once again. Repeat the process by selecting next carriers until $P_s \ge Q_s$ & $PIth_s \ge QIth_s$. However, for $P_s \ge P_T$ & $PIth_s \ge I_{th}$ & $Q_s \le Q_T$ & $QIth_s \le I_{th}$, if $P_s > Q_s$ & $PIth_s > QIth_s$, we select the carriers turn wise and remove the bits as $\bar{b}_{k^*} = \bar{b}_k - 1$. At each step, update the power and hence the data rate to check the validity of all constraints. Similar procedure is followed for the remaining two cases $P_s \le P_T$ & $PIth_s \le I_{th}$ & $Q_s \ge Q_T$ & $QIth_s \ge I_{th}$ and $P_s \ge P_T$ & $PIth_s \ge I_{th}$ & $Q_s \ge Q_T$ & $QIth_s \ge I_{th}$, respectively.

**Algorithm 4**

```
if ($Q_s > P_s$)
   I. Find $c_k$= $\bar{E}(\hat{b}_k-1,\bar{p}_k) - \bar{E}(\hat{b}_k,\bar{p}_k) \quad \forall k$.
   II. Repeat steps II and III of Algorithm 3.
   III. Update $\bar{q}_k = \bar{E}(\hat{b}_{k^*},\bar{p}_{k^*})$ and $\bar{p}_k = \bar{F}(\hat{b}_{k^*},\bar{E}(\hat{b}_{k^*},\bar{p}_{k^*}))$.
   IV. Calculate $Q_s$, $P_s$, $QIth_s$, and $PIth_s$.
else
   V. Find $c_k$= $\bar{F}(\hat{b}_k+1,\bar{q}_k) - \bar{E}(\hat{b}_k,\bar{q}_k) \quad \forall k$.
   VI. Get $k^* = \arg\ \min_k\ c_k$.
   VII. Update $\hat{b}_{k^*} = \hat{b}_{k^*}+1$
   VIII. Repeat steps VIII and IX of Algorithm 2.
end if
```

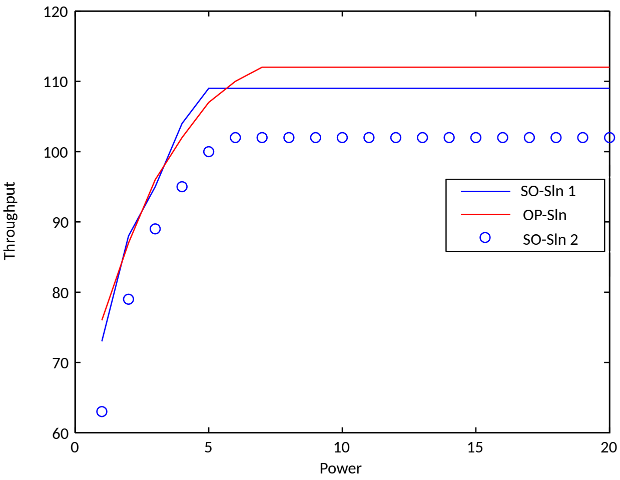

Figure 2. Throughput versus Power

## IV. SIMULATION RESULTS

In this section we provide simulation results to evaluate the performance of our proposed algorithms. We present the numerical solutions with single relay capability and assume Raleigh fading channel for each link. The noise variances and total available powers ($P_T$ and $Q_T$) are set same for source and relay nodes transmission. Further, it is worth mentioning here that the resource allocation was obtained from high SNR approximation, however, in the simulation, performance is evaluated based on the actual expressions. The proposed schemes are;

**OP-Sln:** The proposed solution presented in Algorithm 1.

**SO-Sln 1:** The suboptimal scheme discussed in section III-A.

**SO-Sln 2:** A non-optimal solution based on equal power allocation for the dual hop system, where at each node power is equally distributed among the carriers subject to the conditions that all constraints must be satisfied.

Figure 2 shows the effect of changing the total power budget on the throughput of the OP-Sln, SO-Sln 1 and the non-optimal SO-Sln 2. When power is 1w, the throughput for the OP-Sln is 74 bps and for SO-Sln 1 is 71 bps. However, data rate for SO-Sln 2 is only 65 bps. It can be seen from the curves that if the available power is increased then the throughput of all schemes increases at first and becomes constant after a point. It happens because after this point if the power consumption of any scheme would increase the interference constraint would be violated. From Fig. 2, it can be concluded that the proposed SO-Sln 1 gives better results than the non-optimized SO-Sln 2 but OP-Sln outperforms the other two candidates. It is interesting to note that for some lower power values, SO-Sln 1 also leads OP-Sln but overall performance of OP Sln is best compared to the other proposed schemes.

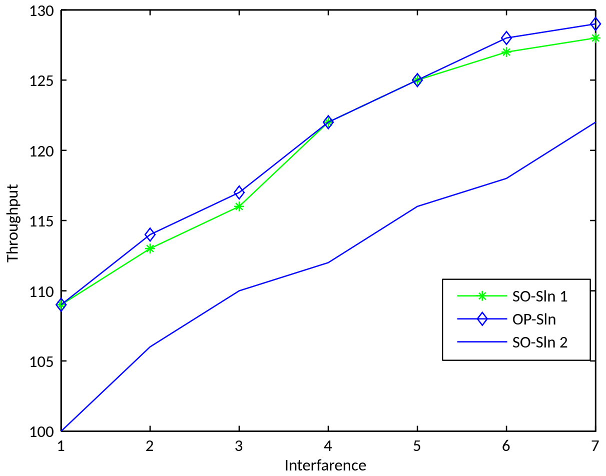

Figure 3. Throughput versus Interference

The performance of the proposed solutions by keeping the power budget (i.e., $P_T$ and $Q_T$) constant while varying the interference is presented in Fig. 3. Nonetheless, all other parameters are kept same as for the previous results. It can be seen that if sufficient power is available, the increasing interference threshold increases the throughput for all the schemes as more chances are there to allocate more power at each node. The proposed algorithm offers more throughput compared to the remaining schemes which proves the superiority of the proposed scheme.

## V. CONCLUSION

In this paper we maximized end to end rate of a relay aided OFDM based CR network under independent interference constraint at each node. The mix integer optimization problem was decomposed into subproblems for ease in solution without compromising on optimality. A joint power allocation and bit loading based solution was proposed. At the end, simulation results were presented to prove the superiority of proposed scheme over sub-optimal schemes and the trivial solution.

## REFERENCES

[1] J. Mitola and G. Q. Maguire Jr, "Cognitive radio: making software radios more personal," in *IEEE Personal Commun.,* vol. 6, no. 4, pp. 1318, Aug. 1999.

[2] I. F. Akyildiz, W. y. Lee, M. C. Vuran and S. Mohanty, "A survey on spectrum management in cognitive radio networks," in *IEEE Commun. Magazine*, vol. 46, no. 4, pp. 40-48, April 2008.

[3] F. Gao, T. Cui, and A. Nallanathan, "On channel estimation and optimal training design for amplify and forward relay network," in *IEEE Trans. Wireless Commun.*, vol. 7, no. 5, pp. 1907–1916, May 2008.

[4] F. Gao, R. Zhang, and Y.-C. Liang, "Channel estimation for OFDM modulated two-way relay networks," in *IEEE Trans. Signal Processing,* vol. 57, no. 11, pp. 4443–4455, Nov. 2009.

[5] K. Hassan, G. Sidhu, and W. Henkel, "Multiuser MIMO-OFDMA with different QoS using a prioritized channel adaptive technique," in *IEEE Int. Conf. on Commun.,* pp.1–5, Dresden, Germany, June 2009.

[6] K. Kwak and C. Zhao , "Power/bit loading in OFDM-based cognitive networks with comprehensive interference considerations: the single-su case," in *IEEE Trans. on Vehicular Tech.*, vol. 59, pp. 19101922, May 2010.

[7] J. Tang, Y. Rahulamathavan, and S. Lambotharan, "Optimal adaptive bit loading and subcarrier allocation techniques for OFDM based cognitive radio systems," in *IEEE Int. Conf. on Commun. Tech. (ICCT)*, pp. 454-457, Nanjing, China, Nov. 2010.

[8] E. Bedeer, M. Marey, O. Dobre, and K. Baddour, "Adaptive bit allocation for OFDM cognitive radio systems with imperfect channel estimation," in *IEEE Symposium on Radio and Wireless(RWS)*, pp. 359-362, Santa Clara, CA, USA, Jan. 2012

[9] E. Bedeer, O. A. Dobre, M. H. Ahmed and K. E. Baddour, "Optimal bit and power loading for OFDM systems with average BER and total power constraints," in *IEEE Global Commun. Conf. (GLOBECOM)*, pp. 3685–3689, Anaheim, CA, USA, Dec. 2012.

[10] B. Gui and L. J. Cimini Jr, "Bit loading algorithms for cooperative ofdm systems," in *IEEE Military Commun. Conf.*, pp. 1–7, Orlando, FL, USA, Oct. 2007.

[11] O. Amin and M. Uysal, "Optimal bit and power loading for amplify-and-forward cooperative OFDM systems," in *IEEE Trans. on Wireless Commun.,* vol. 10, no. 3, pp. 772–781, March 2011.

[12] G. A. S. Sidhu, F. Gao, W. Wang, and W. Chen, " Resource allocation in relay aided OFDM cognitive radio networks," in *IEEE Trans. on Vehicular Tech.*, vol. 62, no. 8, pp. 37003710, 2013

[13] T. Jabeen, G. Sidhu, and F. Gao, "A unified power allocation framework for bidirectional cognitive radio communication," to appear in *IEEE Trans. Veh. Technol.*, 2016.

[14] W. Yang and X. Zhao, "Robust resource allocation for orthogonal frequency division multiplexing-based cooperative cognitive radio networks with imperfect channel state information," in *IET Commun.*, vol. 11, no. 2, pp. 273-281, 2017.