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Resource Allocation in Decode-and-Forward Relaying Systems Based on OFDM

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***Abstract*—In this paper, we investigate resource allocation algorithms for Orthogonal Frequency Division Multiplexing (OFDM) based dual hop systems including a source, multiple relays, and multiple destinations and utilizing Decode-and-Forwarded (DF) relaying. The main objective is to maximize the spectral efficiency under the total power constraint. We first propose an algorithm which simultaneously allocates transmission power and transmission time used by each hop in every time frame. Then we propose a more tractable algorithm which decomposes the original problem in two subproblems. The first subproblem is to solve the optimization problem for a given value of transmission time used by each hop, and the second subproblem is to compute the value of transmission time. The discussed algorithms are also compared with each other and with other resource allocation schemes. Simulation results are also provided which verify the performance improvement by adopting of the proposed algorithms.**

I. Introduction

There are many advantages for multi hop wireless networks over the conventional wireless networks such as coverage extension, enhancing spectrum efficiency and diversity gain [1]. Therefore, they are considered recently in design and development of the broadband wireless networks. Orthogonal Frequency Division Multiplexing (OFDM) is also considered as physical layer technology in such networks [2]. It divides the available bandwidth into the orthogonal subcarriers which deals the frequency selectivity of the wireless channel. By adding a Cyclic Prefix (CP) with a length longer than the maximum delay spread of the wireless channel to each OFDM symbol, the Inter Symbol Interference (ISI) caused by multi-path can be significantly reduced. This advantages have drew attention to OFDM relay systems in recent years and many methods have been introduced for resource allocation in such systems, see, e.g., [3].

Decode and Forward (DF) and Amplify and Forward (AF) relaying techniques are two main forwarding schemes which have been extensively used in multihop OFDM relay systems [4]. Considering such systems, it is shown that when data is transmitted through two or three hop paths, significant gain on throughput is obtained [5].

Radio resource allocation is a very important topic in multihop OFDM systems which has been considered in the related literature, see,e.g., [6], [7], [8]. the difficulty of the resource allocation is the non convexity of the problem caused by the interrelationship of all resources. In such research studies, optimal radio resource allocation is considered and classic methods such as Lagrange multiplier and dual decomposition is then adopted to find/approximate the optimal solution. In [6], power and subcarrier allocation is conducted with the objective of total rate maximization. In [6], separate power constraints are considered for Base Station (BS) and intermediate relays. In cases when the corresponding Relay Station (RS) channel suffers bad condition, allocation more transmit power to this relay in [6], doesn't result in throughput improvement. In [7], a suboptimal algorithm is proposed that first performs relay selection based on corresponding channel conditions and then allocate the power.

It is shown in [9], the computation complexity of such algorithms is linearly increased by increasing number of subcarriers. It is further shown in [10], that when the average fading gains are unbalanced, optimization of the power allocation gives a better performance.

Without considering subcarrier reuse in multihop system along with a source destination path, increasing number of relays does not always result in total transmission power reduction particularly in high transmission rates [11], [12]. Moreover, when the relay operates in time division mode, power allocation provides a significant gain [13]. In [14], one approach is proposed which finds the power and time allocation and exploits the quasi-convexity of the power and time allocation. Proposed modified orthogonal AF cooperation provides a large achievable rate region. In [15] another approach is proposed which finds the power and frame time allocation for each user and obtained time diversity and relatively good spectral efficiency.

In this paper, we consider a system which consists of one source, multiple relays, and multiple destinations and propose two algorithms that allocate power, and transmission time for preassigned subcarriers.

We first consider joint allocation of power and transmission time for a multiuser system. We then decompose the original problem in two subproblems: determining power allocation for a given transmission time allocation to maximize the spectral

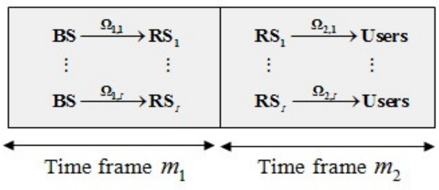

Fig. 1. Time frame structure

efficiency under total power constraint; determining optimal transmission time used by each hop. It is assumed that the relay strategy is DF.

The contribution of this paper is to formulate the optimization of power and transmission time used by each hop in the downlink of dual-hop OFDM relaying systems. This allocation is implemented when the first time interval that is assigned to the transmission of BS and second interval that is assigned to the transmission of relay station have different size.

This paper is organized as follows. Section II presents system model and assumptions. The end to end spectral efficiency over dual hop relaying system under two algorithms is derived in Section III. In Section IV, the simulation results for the proposed relaying schemes are demonstrated. The last section summarizes the findings and provides the conclusions.

II. System model

We consider a system consisting of one source, multiple users, and a set $\mathcal{I} = \{1,\ldots,I\}$ of relays. Let $\mathcal{N} = \{1,2,\ldots,N\}$ denotes the set of orthogonal subcarriers and in each hop transmission is through *N* orthogonal subcarriers. It is assumed that the perfect Channel Side Information (CSI) is available, which enables relay systems to allocate power dynamically on each subchannels. The source performs channel resource (transmission time) and power allocation for such a system. In this paper, we assume that the channel is block fading and channel gain is invariant during the entire time frame but is variant from one frame to another one. it is also assumed that channel between the BS and RS is Line Of Sight (LOS) [5].

In the proposed system the transmission time is divided in to frames consisting of multiple time slots. Fig. 1 shows the overall downlink frame structure. The BS transmits data to RS_i on subchannel set $\Omega_{1,i}$ $(1 \leq i \leq I)$ in time frame m_1. Similarly, RS_i transmits data to the users associated with RS_i on subchannel set $\Omega_{2,i}$ in time frame m_2.

As we know, the instantaneous transmission rate of the relay *i* over hop *k* on subcarrier *n* in m_k time frame is [12],

$$r_{n,k,i} = m_k \log_2(1 + \frac{|h_{ik,n}|^2 p_{ik,n}}{\Gamma N_0 \frac{\omega}{N}}), \quad (1)$$

TABLE I
System Model Parameters

Notation	Definition
$h_{ik,n}$	Channel gain of *ith* relay over *kth* hop on *nth* subcarrier
$p_{ik,n}$	Allocated power of *ith* relay over *kth* hop on *nth* subcarrier
m_k	Fraction of time frame that is allocate to *kth* hop
$\Omega_{k,i}$	subcarrier set that is assigned to *ith* relay over *kth* hop
P_{Total}	Total transmission power

where the parameters are defined in TABLE I.

In this work, $\gamma_{ik,n} = \frac{|h_{ik,n}|}{\Gamma N_0 \frac{\omega}{N}}$ is defined as the normalized channel gain, where N_0 is the power spectral density of the Additive White Gaussian Noise (AWGN), ω is total bandwidth, and Γ is Signal to Noise Ratio(SNR) gap which is a function of Bit-Error-Rate (BER) [16]:

$$\Gamma = \frac{-\ln(5\mathrm{BER}\ )}{1.5}. \quad (2)$$

Note that, $\gamma_{ik,n}$ is known since perfect channel state information is assumed to be available.

III. Problem formulation

In this paper, we assume that the current state of the channels over each hop is available. The end-to-end spectral efficiency is used to capture the system performance. We first propose an algorithm which simultaneously allocates transmission power and transmission time used by each hop in every time frame by using Lagrangian multipliers and Karush-Kuhn-Tucker (KKT) conditions. Next we propose an algorithm which decomposes the original resource allocation problem in two subproblems then we solve this two simpler subproblems.

To perform power and time frame allocation, we first preassign subchannels to RSs and users. In this paper we focus on power and time frame allocation and for subcarrier allocation, we use the modified version of the algorithm which has been proposed in [7], [9].

The optimal resource allocation algorithm for spectral efficiency maximization problem assigns each subchannel to the user with the highest subchannel SNR. Since the number of subchannels in the first hop is the same as the number of subchannels in the second hop, there are N^2 possible subcarrier pairs (n_1, n_2). For subcarrier allocation we compute the equivalent channel gain for all possible subcarrier pairs for each relay i, i.e.,

$$\frac{1}{\gamma^{eq}_{i,n_1,n_2}} = \frac{1}{\gamma_{i1,n_1}} + \frac{1}{\gamma_{i2,n_2}}.$$

The relay which has the highest equivalent channel gain occupies this pair, and we have $\gamma^*_{n_1,n_2} = \max_i \left\{\gamma^{eq}_{i,n_1,n_2}\right\}$. Then we form an $N \times N$ matrix $M = \left[\gamma^*_{n_1,n_2}\right]_{N\times N}$. As we know in each hop a subcarrier can be assigned to one relay, but this matrix has N^2 elements so we must use one method which can select one element from each row and each column. Hungarian method that always selects the maximum element at each time is used for achieving this goal.

A. alg1: Simultaneous power and transmission time allocation, regarding transmission time as an optimization variable

For the system proposed here, in the time frame m_1, data is transmitted to relay i through $\Omega_{1,i}$ subcarriers, while in the time frame m_2, data received in relay i is transmitted to the destination through $\Omega_{2,i}$ subcarriers. Data transmission in two time frame is on the N Subcarriers. Therefore, the rate associated with relay i is as follows,

$$\min\{\sum_{n\in\Omega_{1,i}} r_{n,i,1}, \sum_{n\in\Omega_{2,i}} r_{n,i,2}\}. \tag{3}$$

The problem is to maximize the spectral efficiency under a total power constraint. Therefore, the optimization problem can be written as:

$$\max_{p_{ik,n},m_k} \sum_{i=1}^{I} \min\{\sum_{n\in\Omega_{1,i}} r_{n,i,1}, \sum_{n\in\Omega_{2,i}} r_{n,i,2}\}, \tag{4}$$

$$\text{s.t. } \sum_{i=1}^{I}\sum_{k=1}^{2}\sum_{n\in\Omega_{k,i}} m_k p_{ik,n} \leq P_{Total}, \tag{5}$$

$$\sum_{k=1}^{2} m_k = 1. \tag{6}$$

This problem is not convex. By defining $p^*_{ik,n}$ which turns the power constraint in (5) into a linear and also by introducing variables r_i for $i \in \mathcal{I}$, the above optimization problem turned in to a convex one:

$$\max_{p^*_{ik,n},m_k} \sum_{i=1}^{I} r_i \tag{7}$$

$$\text{s.t. } r_i \leq m_1 \sum_{n\in\Omega_{1,i}} \log_2(1+\frac{\gamma_{i1,n}p^*_{i1,n}}{m_1}) \quad \forall i, \tag{8}$$

$$r_i \leq m_2 \sum_{n\in\Omega_{1,i}} \log_2(1+\frac{\gamma_{i2,n}p^*_{i2,n}}{m_2}) \quad \forall i, \tag{9}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{2}\sum_{n\in\Omega_{k,i}} p^*_{ik,n} \leq P_{Total}, \tag{10}$$

$$\sum_{k=1}^{2} m_k = 1. \tag{11}$$

We then use Lagrange method to solve the above optimization problem. The corresponding Lagrangian over domain $\mathcal{D}$ is:

$$J(r,p^*,m,\mu,\beta,\lambda)$$
$$= \sum_{i=1}^{I} r_i + \sum_{k=1}^{2} \mu_{k,i}(\sum_{n\in\Omega_{k,i}} m_k \log_2(1+\frac{\gamma_{ik,n}p^*_{ik,n}}{m_k}) - r_i)$$
$$+\beta(P_{Total} - \sum_{i=1}^{I}\sum_{k=1}^{2}\sum_{n\in\Omega_{k,i}} p^*_{ik,n}) + \lambda(1-\sum_{k=1}^{2} m_k), \tag{12}$$

where $\mu_{k,i}(i\in\mathcal{I}, k=\{1,2\}), \lambda, \beta \geq 0$, are the Lagrange multipliers and the domain $\mathcal{D}$ is the set of all non-negative $p^*_{ik,n}\,(\forall i \in \mathcal{I}, n\in N, k=\{1,2\})$.

Since the primal problem is convex, the optimal solution should satisfy the KKT conditions [17]. The KKT conditions are:

$$\frac{\partial J(...)}{\partial r_i} = 1 - \sum_{k=1}^{2} \mu_{k,i} = 0, \forall i \in \mathcal{I}, \tag{13}$$

$$\frac{\partial J(...)}{\partial p^*_{ik,n}} = \frac{\mu_{k,i}\gamma_{ik,n}}{1+\frac{\gamma_{ik,n}p^*_{ik,n}}{m_k}} - \beta = 0, \forall i\in\mathcal{I}, \forall n \in \mathcal{N}, k=1,2, \tag{14}$$

$$\frac{\partial J(...)}{\partial m_k}$$
$$= \mu_{k,i}\left\{\sum_{n\in\Omega_{k,i}}\left[\ln\left(1+\frac{\gamma_{ik,n}p^*_{ik,n}}{m_k}\right) - \frac{\gamma_{ik,n}p^*_{ik,n}}{m_k+\gamma_{ik,n}p^*_{ik,n}}\right]\right\}$$
$$-\lambda = 0, \forall i \in \mathcal{I}, k=1,2. \tag{15}$$

By using (14) the optimal power allocation is:

$$p^*_{ik,n} = (\frac{\mu_{k,i}}{\beta} - \frac{1}{\gamma_{ik,n}})^+ m_k, \quad \forall i, \tag{16}$$

substituting (16) in to KKT condition (15), we express λ as a function of $\mu_{k,i}$, and β for all $\forall i \in \mathcal{I}$,

$$\lambda = f_k(\mu_{k,i},\beta,\gamma)$$
$$= \mu_{k,i}\sum_{n\in\Omega_{k,i}}\left\{\left[\ln\left(\frac{\gamma_{ik,n}\mu_{k,i}}{\beta}\right)\right]^+ - \left(1-\frac{\beta}{\gamma_{ik,n}\mu_{k,i}}\right)\right\}. \tag{17}$$

The derivative of the function $f_k(\mu_{k,i},\beta,\gamma)$ with respect to the $\mu_{k,i}$ in the region $[\min_n(\frac{\beta}{\gamma_{ik,n}}), +\infty]$ is positive, therefore it is a monotonically increasing function of $\mu_{k,i}$. Hence, the inverse function $\mu_{k,i} = f_k^{-1}(\lambda,\beta,\gamma)$ exists and is an increasing function of λ. The exact value of $\mu_{k,i}$ for a given λ can be obtained numerically using binary search. Substituting $\mu_{k,i} = f_k^{-1}(\lambda,\beta,\gamma)$ in to (13) we have:

$$\sum_{k=1}^{2} f_k^{-1}(\lambda,\beta,\gamma) = 1, \tag{18}$$

thus the optimal λ can also be obtained via binary search from (18). Finally for finding β, we use the total power constraint, in fact there exist a unique β such that a total power constraint satisfied.

As we know for achieving the optimal solution to (4), the instantaneous rates over all hops, r_ks, at each time frame must be equal [11]. The above result will enable us to find the optimal value of $m_k\,(k\in\{1,2\})$ for all $i\in\mathcal{I}$:

$$m_1\sum_{n\in\Omega_{1,i}}\log_2\left(1+\frac{\gamma_{i1,n}p^*_{i1,n}}{m_k}\right)=m_2\sum_{n\in\Omega_{2,i}}\log_2\left(1+\frac{\gamma_{i2,n}p^*_{i2,n}}{m_k}\right), \quad (19)$$

substituting (16) in to (19) and by using $\sum_{k=1}^{2} m_k = 1$, the optimal value of $m_k\,(k\in\{1,2\})$ will be obtained.

B. alg2: Decomposing power and transmission time allocation problem in two subproblems

In this section, first the optimal power allocation for a given value of $m_k\,(k\in\{1,2\})$ is obtained, then the optimal $m_k\,(k\in\{1,2\})$ is calculated. Therefore for a distinct m_k, the convex optimization problem (7) can be written as:

$$\max_{p^*_{ik,n}} \sum_{i=1}^{I} r_i \quad (20)$$

$$\text{s.t. } r_i \le m_1 \sum_{n\in\Omega_{1,i}} \log_2(1+\frac{\gamma_{i1,n}p^*_{i1,n}}{m_1}) \;\; \forall i, \quad (21)$$

$$r_i \le m_2 \sum_{n\in\Omega_{1,i}} \log_2(1+\frac{\gamma_{i2,n}p^*_{i2,n}}{m_2}) \;\; \forall i, \quad (22)$$

$$\sum_{i=1}^{I}\sum_{k=1}^{2}\sum_{n\in\Omega_{k,i}} p^*_{ik,n} \le P_{Total}. \quad (23)$$

The Lagrangian of (20) over domain $\mathcal{D}$ is:

$$J(r,p^*,m,\mu,\beta,\lambda)$$
$$=\sum_{i=1}^{I} r_i + \sum_{k=1}^{2}\mu_{k,i}(\sum_{n\in\Omega_{k,i}} m_k\log_2(1+\frac{\gamma_{ik,n}p^*_{ik,n}}{m_k})-r_i)$$
$$+\beta(P_{Total}-\sum_{i=1}^{I}\sum_{k=1}^{2}\sum_{n\in\Omega_{k,i}} p^*_{ik,n}), \quad (24)$$

where $\mu_{k,i},(i\in\mathcal{I},k=\{1,2\}),\beta\ge 0$, are the Lagrange multipliers and the domain $\mathcal{D}$ is the set of all non-negative $p^*_{ik,n}\,(\forall i\in\mathcal{I},n\in N,k=\{1,2\})$.

The optimal solution of (24) also satisfies the KKT conditions. So from the gradient of the Lagrangian, we have:

$$p^*_{ik,n}=\left(\frac{\mu_{k,i}}{\beta}-\frac{1}{\gamma_{ik,n}}\right)^+ m_k, \forall i, \quad (25)$$

$$\sum_{k=1}^{2}\mu_{k,i}=1, \forall i\in\mathcal{I}. \quad (26)$$

For solving the power allocation problem, Algorithm 1 is presented. In this algorithm, $\frac{1}{\beta}=t_1$, $\frac{\mu_{1,i}}{\beta}=t_0(i)t_1$, and $\frac{\mu_{2,i}}{\beta}=(1-t_0(i))t_1$ for all $i\in\mathcal{I}$, are water levels. The expression in Algorithm 1 provides the optimal power allocation for a given value of time frame $m_k\,(k\in\{1,2\})$.

The process for adjusting t_1 is performed until the power distribution satisfies (23), and the process for adjusting $t_0(i)$ is performed until the sum rate in the first hop becomes equal the sum rate in the second hop.

Algorithm 1: Power allocation algorithm

Given T_1,T_2 and $H_{t_1}=T_1, L_{t_1}=0$ the following relations are used to obtain $\mu_{1,i},\mu_{2,i},(i\in\mathcal{I}),\beta$.

1) $t_1=(H_{t_1}+L_{t_1})/2$, do steps 2-5 for each relay *i*.
2) $H_{t_0}(i)=t_1, L_{t_0}(i)=0$, do ***a***.
- ***a.1*** $t_0(i)=(H_{t_0}(i)+L_{t_0}(i))/2$
- ***a.2*** $p^*_{i1,n}=(t_1t_0(i)-1/\gamma_{i1,n})^+m_1$
- ***a.3*** $r_{i,1}=m_1\sum_{n\in\Omega_{1,i}}\log_2(1+\gamma_{i1,n}p^*_{i1,n}/m_1)$
- ***a.4*** $p^*_{i2,n}=(t_1(1-t_0(i))-1/\gamma_{i2,n})^+m_1$
- ***a.5*** $r_{i,2}=m_2\sum_{n\in\Omega_{2,i}}\log_2(1+\gamma_{i2,n}p^*_{i2,n}/m_2)$

3) $error_0=r_{i,1}-r_{i,2}$
4) if $error_0>0,\ H_{t_0}(i)=t_0$ else $L_{t_0}(i)=t_0$
5) if $H_{t_0}(i)-L_{t_0}(i)>\epsilon$, return to ***a***.
6) $error_1=\sum_{i=1}^{I}\left(\sum_{n\in\Omega_{1,i}}p^*_{i1,n}+\sum_{n\in\Omega_{2,i}}p^*_{i2,n}\right)-2P_{Total}$
7) if $error_1>0,\ H_{t_1}=t_1$ else $L_{t_1}=t_1$
8) if $H_{t_1}-L_{t_1}>\epsilon$, return to **1**.

However, same time frame allocation for two hops isn't optimal and our goal is to jointly optimize the power and time frame allocation. It is worth mentioning that since the primal problem is convex regarding to m_k, it quickly converges to it's optimal value. Therefore, we use binary bisection method which has a lower complexity for. This method is successfully implemented in [16]. Algorithm 2 calculates transmission time used by each hop, by this method.

Algorithm 2: An algorithm for finding m_k

We assume $m_1=r$, and by using $\sum_{k=1}^{2}m_k=1$ we will have $m_2=1-r$. Given $\xi(r)$ is the optimal value of(20). Set $\xi(0)=\xi(1)=0$ and also $t_0=0$, $t_4=1$ and $t_2=1/2$. Using the optimal power allocation which is proposed in Algorithm 1 and (20), compute $\xi(t_2)$. Given a tolerance ϵ.

1) Set $t_1=(t_0+t_2)/2$ and $t_3=(t_2+t_4)/2$.
2) Using Algorithm 1 and (20), compute $\xi(t_1)$ and $\xi(t_3)$.
3) Find $k^*=\arg\max_{k\in\{0,1,\ldots,4\}}\xi(t_k)$.
4) Replace t_0 by $t_{\max\{k^*-1,0\}}$, replace t_4 by $t_{\min\{k^*+1,4\}}$, and compute $\xi(t_0)$ and $\xi(t_4)$. If $k^*\notin\{0,4\}$ set $t_2=t_{k^*}$ and compute $\xi(t_2)$, else set $t_2=(t_0+t_4)/2$ and use Algorithm 1 and (20) to calculate $\xi(t_2)$.
5) If $t_4-t_0\ge\varepsilon$ return to **1** else set $r^*=t_{k^*}$.

In this algorithm, at each step we use the expression in Algorithm 1 to determine the optimal power allocation for each the $r=m_1$, and $1-r=m_2$. Therefore, after using this algorithm the jointly optimal value for transmission time used by each frame and powers can be obtained.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Cell radius	1000 m
BS height	25m
User terminal height	1.5 m
No. of subcarriers(N)	16
Noise power(N_0)	-159.0 dBm/Hz
Modulation schemes	QPSK
BER	10^{-5}
Doppler shift	0.4 Hz
Bandwidth(ω)	1 MHz
Central frequency	1900 MHz

IV. SIMULATION RESULTS

In this section, results are given for a dual-hop OFDM relaying system with fixed relay station. Simulation parameters are presented in TABLE II.

We assume that the Relay Stations (RS) are located at radius 500m from the BS. Users are uniformly distributed between RSs and cell radius. Each user's channel is modelled as a frequency selective multi path Rayleigh fading with Stanford University Interim channel model [16]. Pathloss is intermediate pathloss condition [18]category B, the pathloss is as follows:

$$P_L = 20\log(4\pi d_0/\lambda) + \alpha\log(d/d_0) \quad [dB],$$

where α is the pathloss exponent that is set to 4.375.

In these simulations, Adaptive Power Uniform Time (APUT), Adaptive Power Adaptive Time (APAT), Adaptive Power Uniform Time (APUT), and Uniform Power Uniform Time (UPUT) are proposed. In the presented results, adaptive refers to the case in which resources are allocated based on presented algorithms while uniform refers to the case in which power is distributed uniformly among subcarriers or time is distributed uniformly among hops, i.e. $m_1 = m_2 = 0.5$.

Fig. 2 shows the spectral efficiency versus total transmission power. In this simulation, the number of users is 4, and subcarriers are preassigned to RSs and users. It can be seen the dual hop relay system with the proposed APAT scheme achieves much higher performance compared to the existing resource allocation methods with APUT scheme and no consideration for transmission time allocation. We simulate APAT scheme for two proposed algorithms, as can be seen two proposed algorithms have the same performance. Therefore in rest of simulations we use algorithm 1, which has lower complexity and is more tractable.

Fig. 3 illustrates spectral efficiency for multiuser system. It shows that the resource allocation method with APAT scheme has better performance compared to the APUT scheme in multiuser system with large number of the users. As it can be seen by increasing the number of users the spectral efficiency also increases but the improvement in spectral efficiency is diminishing when the number of users is large enough.

Fig. 4 shows time frame ratio for multiuser system where the number of users is 4 and power and transmission time are distributed with APAT scheme. This figure depicts the

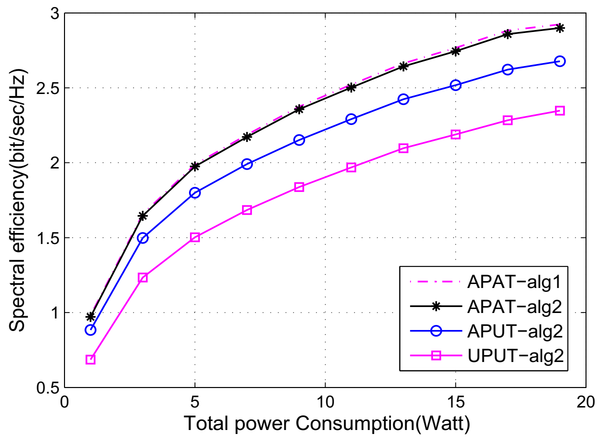

Fig. 2. Spectral efficiency versus total transmission power, the number of users in algorithms is 4.

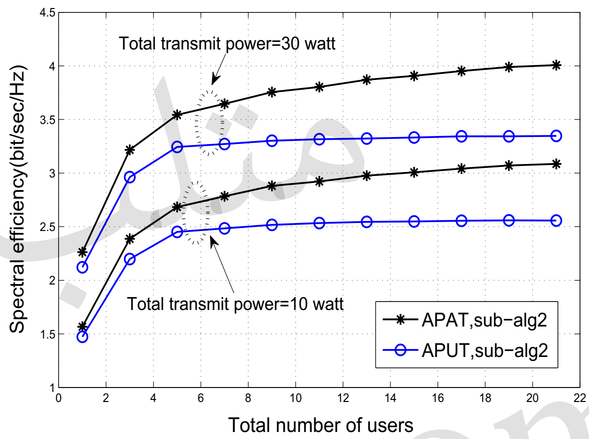

Fig. 3. Spectral efficiency achieved by different algorithms with different number of users.

improvement in spectral efficiency in systems with adaptive transmission time allocation compared to the systems with uniform transmission time allocation. We also can see the improvement in spectral efficiency is diminishing when the total transmission power is so high.

V. CONCLUSION

In this paper, the resource allocation in a dual hop Orthogonal Frequency Division Multiplexing (OFDM)relaying downlink system has been considered. Two algorithms for power and time frame allocation under total power constraint have been proposed. We first proposed an algorithm which simultaneously allocates transmission power and transmission time used by each hop in every time frame. Then we proposed a more tractable algorithm which decomposes the original problem in two subproblems. We utilized Lagrange method to solve the problems. To verify the performance of the proposed algorithms, The obtained results have been compared with the existing resource allocation schemes.

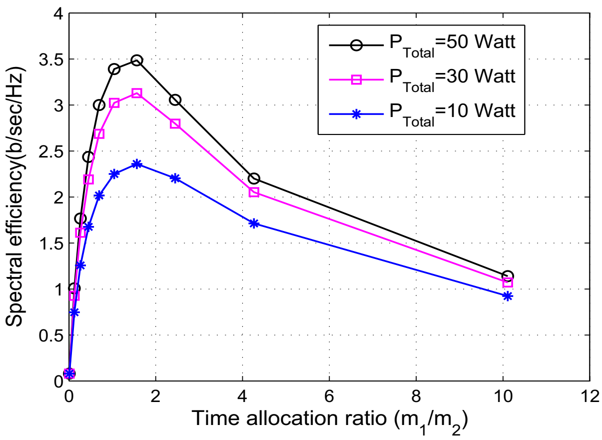

Fig. 4. Spectral efficiency achieved with different time allocation ratio, the number of users is 4.

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