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Multi-Relay Selection Based Resource Allocation in OFDMA System

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Abstract: *OFDMA (Orthogonal Frequency Division Multiple Access) is a popular multiple access technique which is used in many present day communication systems. It is a multiuser variant of OFDM, providing high data rate transmission than OFDM based systems. For providing better data rates at cell edges intermediate nodes known as relay nodes are incorporated between the source and destination. Thus a promising technique known as Cooperative relaying is used for OFDMA based communication systems to improve the coverage area and to increase the capacity at the cell edges. Also by adaptively allocating subcarriers and power to users the system performance can be dramatically enhanced. Thus the joint optimization problem constitutes effective power allocation, subcarrier assignment and relay selection. Propose multi-relay based resource allocation for multiuser OFDM system. In this study, dual decomposition algorithm is used to solve the joint optimization problem with the objective to maximize the capacity of the system. Result shows that the proposed system improves the system capacity.*

Keywords: *Cooperative relaying, Multi Relay Selection, Resource Allocation, Joint Optimization, System Capacity, OFDMA*

I. INTRODUCTION

Orthogonal Frequency Division Multiple Access (OFDMA) is the leading multi-access technology in present wireless networks. This will helps to improve the spectral efficiency and system performance. In OFDMA, major problem is facing at cell edges due to the lack of data rates. This issue can be solved by introducing the relays. Relays are the intermediate nodes which used in between the source and the destination. The signals from the source are received by the relay nodes and then forwards to the destination after the proper amplification or decoding. Thus cooperative communication came forward to extend the system coverage and increases the spectrum efficiency. In cooperative communication, two types of relays are used –fixed relays and mobile or user relays. Deployment of the fixed relays causes increased power consumption; this will reduces the energy efficiency and increase the cost. This issue can be solved by using mobile users as relays which will help to improve the coverage area[1].

Resource allocation plays an important role in cooperative OFDMA system. In cooperative communication, proper relay selection, allocation of subcarriers and power will dramatically increases the system performance [2]. So, in relay selection, choosing the right nodes to cooperatively transmit at the right time is critical. For example, if the channel between the source and the relay or the channel between the relay and the destination is in a deep fade, cooperative transmission wastes precious system resources. Thus the proper selection of the relay can achieve higher throughput or lower error probability [3]. Increasing the number of relays also increases the diversity gain and flexibility of the network. Therefore, multi-relay selection will gives an increased system capacity than the single relay one. In this paper, we propose a multi relay selection based resource allocation in OFDMA system. The joint optimization problem constitutes the effective power allocation, subcarrier assignment and multi relay selection. Our objective is to maximize the capacity of the system. The problem is a mixed integer nonlinear program (MINLP), which is in general very difficult to solve. So, the problem is solved by using a dual decomposition method which is computationally efficient.

This paper is organized as follows: Section II introduces basic system model. It is followed by section III which contains the problem and its solution approach. In section IV the proposed relay selection and subcarrier allocation is discussed. In section V the obtained results are discussed followed by concluding remarks in section VI.

II. SYSTEM MODEL

Consider an OFDMA downlink single-cell network where the base station (BS) is placed at the center of the cell. System consisting of N orthogonal subcarriers, each of them with a bandwidth of W is considered. As shown in the fig.1, the cell is divided into two groups of mobile users. R denotes the first group of users and U denotes the second group. The distance between base station and the user is large in the case of U users compared to R users and thus we consider the second group as users and the first group as relays. The BS decides whether to cooperate or not based on the channel conditions. Here, DF relaying protocol is used.

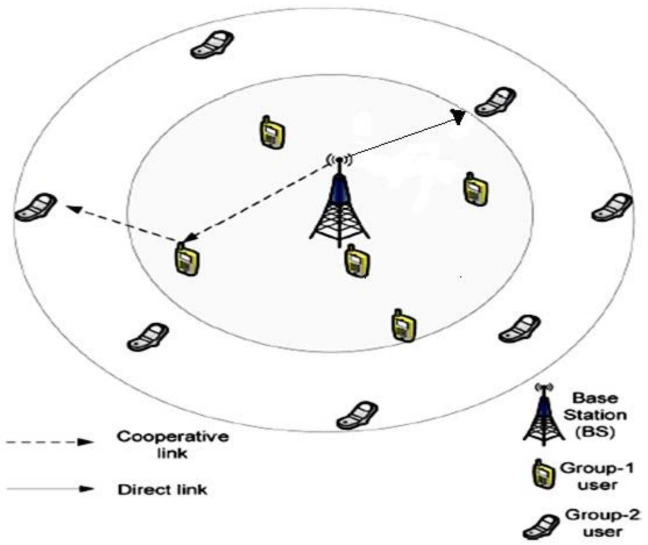

Fig.1. System model for cooperative communication

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III. PROBLEM FORMULATION

The joint optimization problem of subcarrier assignment, power allocation, transmission mode (cooperative or non-cooperative) and multi relay selection is formulated as

$$\max_{P,S,\Phi} \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(c)} R_{r,u}^{i,(c)} + \sum_{k=1}^{K}\sum_{i=1}^{N} d_{u}^{i,(nc)} R_{u}^{i,(nc)} \qquad (1)$$

Subject to:

$$C_1 : \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(c)}\, P_{B,r}^{i,(c)} + \sum_{u=1}^{U}\sum_{i=1}^{N} d_{u}^{i,(nc)} P_{B,u}^{i,(nc)} \leq Pmax$$

$$C_2 : d_{r,u}^{i,(c)}, d_{u}^{i,(nc)} \in \{0,1\}, \;\; \forall\, i, u, r$$

$$C_3 : \sum_{u=1}^{U}\sum_{r=1}^{R} d_{r,u}^{i,(c)} + \sum_{u=1}^{U} d_{u}^{i,(nc)} \leq 1, \;\; \forall i$$

$$C_4 : \Phi_{r,u}^{i,(I)} + \Phi_{r,u}^{i,(E)} = d_{r,u}^{i,(c)}, \;\; \forall i, u, r$$

$$C_5 : \alpha_{B,m}^{i,(c,1)} \Phi_{r,u}^{i,(I)} = \alpha_{B,r}^{i,(c,1)} \alpha_{r,u}^{i,(c,2)} \Phi_{r,u}^{i(E)}, \;\; \forall i, u, r$$

$$C_6 : P_{B,r}^{i,(c)}, P_{B,u}^{i,(nc)}, \Phi_{r,u}^{i,(I)}, \Phi_{r,u}^{i,(E)} \geq 0, \;\; \forall i, u, r$$

$$C_7 : \sum_{u=1}^{U}\sum_{i=1}^{N} d_{r,u}^{i,(c)} \leq n_{m,} \;\; \forall m \qquad (2)$$

where P, Φ and S denote the power allocation, power splitting factors and subcarrier allocation policy, respectively. Here, we consider the receiver as a energy splitting one. At the receiver side the signal from the basestation is divided into two streams: one for harvesting the energy (E) and other for decoding the information (I) with the ratios of $\Phi_{r,u}^{i,(E)}$ and $\Phi_{r,u}^{i,(I)}$, respectively. The relays use the harvested energy only to forward the data to users. Superscript i,(c,1) and i,(c,2) indicate the cooperative transmission mode over subcarrier i in time slot one and two, respectively. $R_{r,u}^{i,(c)}$ and $R_{u}^{i,(nc)}$ indicates the capacity of the cooperative and non cooperative link.

The capacity of the cooperative link can be calculated as

$$R_{r,u}^{i,(c)} = 1/2min\{\log_2\big(1+\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}P_{B,r}^{i,(c)}\big),\ \log_2\big(1+\alpha_{r,u}^{i,(c,2)}\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(E)}P_{B,r}^{i,(c)}\big\} \quad (3)$$

Where, $P_{B,r}^{i,(c)}$ is the transmission power of BS B on subcarrier i over the cooperative link to send the data for relay r. This power attenuated by the fading channel in the first hop is received by relay r as $\alpha_{B,r}^{i,(c,1)}P_{B,r}^{i,(c)}$. The relay splits the received signal into two power streams with the ratios of $\Phi_{r,u}^{i,(I)}$ and $\Phi_{r,u}^{i,(E)}$. In the second time slot, the relay will use the harvested power given by $\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(E)}P_{B,r}^{i,(c)}$ to forward the data for user U. It is assumed that all the energy harvested in first time slot in the relay will be used for forwarding the information in the second time slot. If the direct link is better than the cooperative link, the BS directly transmits data to the user.

The capacity of the direct link is calculated as,

$$R_u^{i,(nc)} = \log_2(1+\alpha_{B,u}^{i,(nc)}P_{B,u}^{i,(nc)}) \quad (4)$$

Where $P_{B,u}^{i,(nc)}$is the transmission power of BS B on subcarrier i over the direct link to user U.

IV. SOLUTION APPROACH

The optimization problem in (1) is a mixed-integer nonlinear program (MINLP).It is so difficult to solve due to some continuous variables with nonlinear functions. The complexity of solving the MINLP problem is reduced by reformulating the problem to a tractable one. Then relax the reformulated problem. The relaxed problem is a non convex one. Define new auxiliary variables to make the problem into a convex one. To tackle the objective function, we then introduce an iterative algorithm known as dual decomposition algorithm. In each iteration of the dual decomposition technique, we solve some subproblems and a master problem. The details of our proposed scheme are given in the following subsections.

A. Introducing the Power Splitting Ratios

Here, we consider multi relay based resource allocation. So, before introducing the power splitting ratios, we have to find the first best relay. Therefore by using the channel conditions, select the first best relay for each subcarrier and then find if the cooperative link is essential or not for the end users. Then obtain the power splitting ratios for each cooperative link from C_4 and C_5 as

$$\Phi_{r,u}^{i,(I)} = \frac{\alpha_{r,u}^{i,(c,2)}}{1+\alpha_{r,u}^{i,(c,2)}} \quad (5)$$

$$\Phi_{r,u}^{i,(E)} = \frac{1}{1+\alpha_{r,u}^{i,(c,2)}}$$

Thus we obtained the splitting factors.

B. Relaxing the Binary Variables and Introducing the Auxiliary Variables

Relax the indicators S in [0,1] interval and define auxiliary power variables as

$$\tilde{P}_{B,r}^{i,(c)} = S_{r,u}^{i,(c)}P_{B,r}^{i,(c)} \quad (6)$$

$$\tilde{P}_{B,u}^{i,(nc)} = S_u^{i,(nc)}P_{B,u}^{i,(nc)}$$

These auxiliary power variables make the optimization problem a tractable one. Thus the resulting problem becomes convex.

C. Solving Optimization Problem in each Iteration of the Dual Decomposition Method

The relaxed optimization problem is convex and strong duality holds, i.e., the duality gap is zero. Thus the optimal solution of the relaxed problem is obtained by solving the Lagrangian dual problem.
The Lagrangian dual problem is formulated as

$$\min_{\lambda\geq 0}\max_{\tilde{P},S} L(\lambda,\tilde{P},S) \quad (7)$$

Where the partial Lagrangian for the relaxed problem is given by,

$$L(\lambda,\tilde{P},S)=\sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(C)}\log_2\left(1+\frac{\alpha_{B,r}^{i,(C,1)}\Phi_{r,u}^{i,(I)}\tilde{P}_{B,r}^{i,(C)}}{d_{r,u}^{i,(C)}}\right)+\sum_{u=1}^{U}\sum_{i=1}^{N} d_{u}^{i,(NC)}\log_2\left(1+\frac{\alpha_{B,u}^{i,(NC)}\tilde{P}_{B,u}^{i,(NC)}}{d_{u}^{i,(NC)}}\right)$$
$$+\lambda\left(P_{max}-\textstyle\sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N}\tilde{P}_{B,r}^{i,(C)}\sum_{u=1}^{U}\sum_{i=1}^{N}\tilde{P}_{B,u}^{i,(NC)}\right) \qquad (8)$$

where $\boldsymbol{\lambda}$ is the non-negative Lagrangian multiplier. We solve the dual problem (7) with dual decomposition technique which is an iterative method. In each iteration of the dual decomposition technique, some subproblems and a master problem is solved. In the subproblems, we optimize ($\tilde{P}$,S) in terms of the given Lagrangian multiplier, and in the master problem the multiplier is updated. The algorithm stops when the multiplier converges. The details of the dual decomposition algorithm are given as

(1) Solving the Subproblems

Solving the subproblems, we obtain the optimal power and subcarrier allocation policy for a given multiplier. The maximization part of the dual problem can be re-written as

$$\max_D \max_{\tilde{P}} L(\lambda,\tilde{P},D) \qquad (10)$$

We first maximize the Lagrangian with respect to $\tilde{P}$ and provide the solution in terms of S. Then we obtain the optimal subcarrier allocation policy S. Using Karush-Kuhn-Tucker (KKT) conditions, obtain the optimal power allocation policy as follows.

$$\tilde{P}_{B,r}^{i,(c)*}=d_{u,r}^{i,(c)}\left[\frac{1}{2\ln(2)\lambda}-\frac{1}{\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)*}}\right]^{+}$$
$$\tilde{P}_{B,u}^{i,(nc)*}=d_{u}^{i,(nc)}\left[\frac{1}{\ln(2)\lambda}-\frac{1}{\alpha_{B,u}^{i,(nc)}}\right]^{+} \qquad (11)$$

To obtain the optimal subcarrier allocation policy (S), we use the optimal power solution $\tilde{P}_{B,r}^{i,(c)*}$ and $\tilde{P}_{B,u}^{i,(nc)*}$ of (11) into the Lagrangian (8). After rearranging, problem (8) can be written as a linear function in terms of (S) given by

$$\max_D \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(c)}\acute{C}_{r,u}^{i,(c,1)}+\sum_{u=1}^{U}\sum_{n=1}^{N} d_{u}^{i,(nc)}\acute{C}_{k}^{i,(nc)} \qquad (12)$$

Subject to C_3 and C_7
Where $\acute{C}_{r,u}^{i,(c,1)}$ and $\acute{C}_{k}^{i,(nc)}$ are given by,

$$\acute{C}_{r,u}^{i,(c,1)}=\frac{1}{2\log_2(1+\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}}$$

$$\left[\frac{1}{2\ln(2)\lambda}-\frac{1}{\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}}\right]^{+})$$
$$-\lambda\left[\frac{1}{2\ln(2)\lambda}-\frac{1}{\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}}\right]^{+}$$

$$\acute{C}_{u}^{i,(nc)}=\log_2(1+\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}$$

$$\left[\frac{1}{\ln(2)\lambda}-\frac{1}{\alpha_{B,u}^{i,(nc)}\Phi_{r,u}^{i,(I)}}\right]^{+})$$
$$-\lambda\left[\frac{1}{\ln(2)\lambda}-\frac{1}{\alpha_{B,r}^{i,(c,1)}\Phi_{r,u}^{i,(I)}}\right]^{+}$$
$$(13)$$

We have satisfied constraints $C_4$and C_5 to obtain optimal power splitting ratios in (5), and C_1 and C_6 in (11) to obtain optimal power allocation policy. The rest of the constraints are incorporated in (12) to obtain the optimal subcarrier allocation policy.

(2) Master problem

$$\lambda(t+1) = [\lambda(t) - \eta(t)(P_{max} - \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{i=1}^{N} \tilde{P}_{B,r}^{i,(c)}$$

$$- \sum_{k=1}^{k}\sum_{i=1}^{N} \tilde{P}_{B,u}^{i,(nc)})]^{+} \qquad (14)$$

Obtain the rate for the first best relay by using the problem in(12). Our aim is to improve the capacity of the system using multi relay selection based resource allocation. So, we have to find the second best relay by using the channel values. Power utilized for the first best relay as follows,

$$P_{\mathrm{maxnew}} = P_{\max} - \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} \tilde{P}_{B,r}^{i,(C)} \sum_{u=1}^{U}\sum_{i=1}^{N} \tilde{P}_{B,u}^{i,(NC)} \qquad (15)$$

Thus the remaining power in (15) is given to the second best relay. Therefore the partial Lagrangian for the relaxed problem is given by,

$$L\left(\lambda, \widetilde{P,S}\right) = \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(C)} \log_2\left(1 + \frac{\alpha_{B,r}^{i,(C,1)} \Phi_{r,u}^{i,(I)} \tilde{P}_{B,r}^{i,(C)}}{d_{r,u}^{i,(C)}}\right) + \sum_{u=1}^{U}\sum_{i=1}^{N} d_{u}^{i,(NC)} \log_2\left(1 + \frac{\alpha_{B,u}^{i,(NC)} \tilde{P}_{B,u}^{i,(NC)}}{d_{u}^{i,(NC)}}\right)$$

$$+\lambda\left(P_{maxnew} - \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} \tilde{P}_{B,r}^{i,(C)} \sum_{u=1}^{U}\sum_{i=1}^{N} \tilde{P}_{B,u}^{i,(NC)}\right) \qquad (16)$$

Then solve the subproblems and master problem in each iteration of the dual decomposition technique for the second best relay. After the allocation of power and subcarrier, the optimization problem can be written as a linear function in terms of (S) given by

$$\max_{D} \sum_{u=1}^{U}\sum_{r=1}^{R}\sum_{i=1}^{N} d_{r,u}^{i,(c)} \acute{C}_{r,u}^{i,(c,1)} + \sum_{u=1}^{U}\sum_{n=1}^{N} d_{u}^{i,(nc)} \acute{C}_{k}^{i,(nc)} \qquad (17)$$

In master problem, we update the multiplier as,

$$\lambda(t+1) = [\lambda(t) - \eta(t)(P_{maxnew} - \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{i=1}^{N} \tilde{P}_{B,r}^{i,(c)}$$

$$- \sum_{k=1}^{k}\sum_{i=1}^{N} \tilde{P}_{B,u}^{i,(nc)})]^{+} \qquad (18)$$

Obtain the rate for the second best relay by solving the problem in (17). For findig the system capacity using multi- relay based resource allocation, add the rate obtained for first and second best relay. Thus the multi-relay selection improves the system capacity than the single relay based resource allocation for OFDMA system.

V. SIMULATION RESULTS

A simulation result shows the effectiveness of our proposed system model and optimization method. We consider a single circular cell with radius 1 km with a ring shape inner boundary with radius 0.5 km which separates the first and second group users. The number of users in each group is 8, i.e., r = u = 8.The users are randomly located in the cell with uniform distribution. The noise power spectral density (N_0) and bandwidth of each subcarrier (W) are assumed to be 5 x10^{-5} Watt/Hz and 20 KHz, respectively. The channel coefficients are independent and identically distributed (i.i.d.) circularly symmetric complex Gaussian random variables.

Fig. 1, shows the bit error rate performance obtained for the implemented OFDMA system.

Fig. 2, shows the average system capacity in terms of the power budget of the BS ($P_{\max}$) for N=64. As shown in the figure, the total capacity of the system grows with the increase of $P_{\max}$

Fig. 3, shows the average system capacity in terms of the power budget of the BS ($P_{\max}$) for different subcarriers. As shown in the figure, the total capacity of the system grows both with the increase of $P_{\max}$ and number of subcarriers.

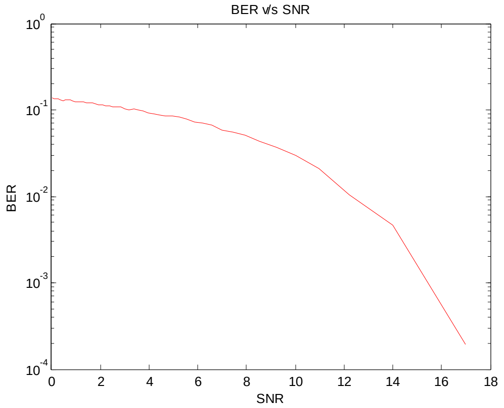

Fig1.BER vs SNR curve for an OFDMA system

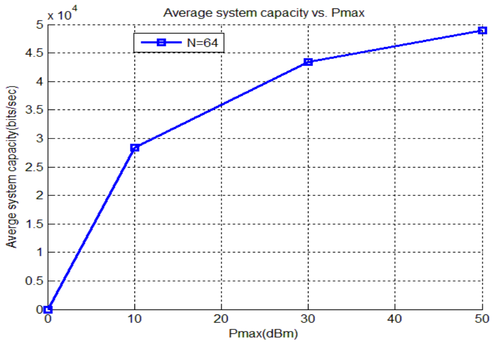

Fig. 2 Average system capacity vs P_{max}

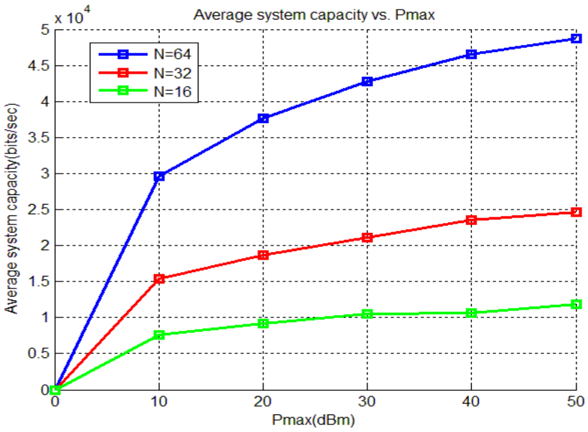

Fig. 3 Average system capacity vs P_{max} for different number of subcarriers

Above results shows the average system capacity in terms of the power budget of the BS(P_{max}) in OFDMA system by using single relay selection method. Increasing the number of relays can increase the diversity gain and flexibility of the network. Thus the multi relay gives a better performance than the single relay. Fig. 4, depicts the average system capacity in terms of the power budget of the BS (P_{max}) using single relay and multi relay selection for N=64. Results shows that the multi relay improves the system capacity than the single relay.

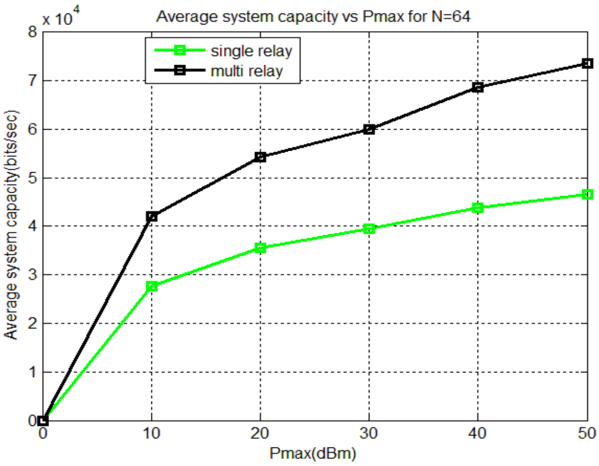

Fig.4 Average system capacity vs Pmax for single and multi relay

VI. CONCLUSION

OFDMA, the most leading technology in present day communication system provides better data transmission than the OFDM system. Performance of the system is improved by the emergence of cooperative communication in OFDMA system. Resource allocation is an optimization problem solved by using various resource allocation algorithms. Thus the joint optimization problem constitutes effective power allocation, subcarrier assignment and relay selection. Relay selection plays an important role in resource allocation, which can achieves higher throughput or lower error probability through one or more relays for transmission according to channel condition. Increasing the number of relays will increase the system capacity. Proposed multi relay based resource allocation for OFDMA system. Proposed methodology is solved by using the computationally efficient dual decomposition algorithm. Thus the multi-relay improves the system capacity than the single relay based resource allocation for multi user OFDM system.

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