Cooperative Relay Based Resource Allocation for OFDMA Network

S. Tamilselvan, R. Gajalakshmi, D. Prabakar

Abstract* — Cooperative relaying is a promising technique for Long Term Evolution Advanced (LTE-A) networks to satisfy high throughput demand and support heterogeneous communication services with diverse quality-of-service (QoS) requirements. Optimal relay selection, power allocation and sub carrier assignment scheme under a total power constrain is proposed for a Qos aware resource allocation for multi user cooperative OFDMA network. The relay selection, power allocation and subcarrier assignment problem are formulated as a joint optimization problem with the objective of maximizing system throughput. User at the cell edge and shadowing degrade the signal quality, hence cooperative relaying is very promising solution to provide better throughput and coverage extension. Combining OFDMA and cooperative relaying assures high throughput enhancement for user at cell edge .Throughput enhancement problem is solved by two level dual composition and sub gradient method. To further reduce the computational cost, low complexity suboptimal schemes are also proposed in this work. Simulation result indicates that the proposed scheme will guarantee the users Qos requirement and maximize the system throughput.

***Index Terms*—OFDMA network, cooperative relaying, relay selection, resource allocation, joint optimization, QoS, LTE-A.**

I. INTRODUCTION

Next generation wireless networks target high data rates, efficient resource usage and economic network deployment. Given the fact that radio resource is becoming a scarce factor in wireless communication the orthogonal frequency division multiple access (OFDMA) has proposed as a state of the art air interface technology to enable high spectrum efficiency . Due to its promising feature , OFDMA is adopted in many emerging cellular system such as the Third Generation Partnership Project (3GPP) ,Long Term Evolution(LTE)[2], LTE-A, LTE-advanced[3]World-wide interoperability for Microwave Access (WiMAX) [4] and so on, to meet high spectral efficiency and to realize the flexibility on access of Radio Resource Management (RRM).The standardization of LTE –Advanced is now underway with the goal of achieving a next-generation high-speed and high capacity mobile communications systems. For LTE-Advanced studies are being made on relay technology for achieving self-backhauling of the radio signal between the base station and mobile.

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S.TAMILSELVAN received his BE in Electronics and communication Engineering from Madras University in 1999 and M.Tech in Electronics and Communication Engineering from the Pondicherry Engineering College in 2001

GAJALAKSHMI.R obtained her B.Tech degree (2011) she is pursuing M.Tech in the Department of Electronics and communication engineering, Pondicherry engineering college, Pondicherry University, Pondicherry, INDIA.

D. PRABAKAR received the B.Tech degree (2007) in the Department of Electronics and Communication Engineering from Arunai Engineering College affiliated to Anna University and M.Tech degree (2009)

This technology aims to improve throughput more efficiently at cell edge A good RRM scheme, including sub carrier allocation scheduling and power control is crucial to guarantee high system throughput for the Performance for OFDMA based network. The main challenges facing in 4G network community is the provision of high throughput for mobile at the cell edge. Choosing the best relay and allocating the resources in an OFDMA relay network with single user and multiple relays have been well studied. In the presence of multiple users and multiple relays, the relay selection and resource allocation problem will be complicated due to the interactions among the users. There have been numerous research works considering the OFDMA systems.[5][6][7] One of the main challenges facing the 4G networking community is the provision of high throughput for mobiles at the cell edge. Users at the cell edge often suffer from bad channel conditions. Moreover, in an urban environment, shadowing by various obstacles can degrade the signal quality significantly. Cooperative relaying is a very promising solution to tackle this problem as it provides throughput gains as well as coverage extension[8][9]. Combining OFDMA and co-operative relaying assures high throughput requirements, particularly for users at the cell edge. Additionally, relaying is considered as a cost effective throughput enhancement in both IEEE 802.16j and LTE-A standards.

Efficient relay selection and resource allocation are crucial in multi-user and multi-relay environment fully exploit the benefits of relaying in 4G networks .However, relay selection is performed for each user and all subcarriers allocated to that user use the same relay, and each user's QoS requirement is not considered in the joint design .A most recent work[10][11] proposed a low complexity suboptimal algorithm for subcarrier assignment, power allocation and partner selection for amplify-forward cooperative multicarrier systems. Resource allocation supporting each user's QoS requirements has been considered in several works .a rate adaptive joint subcarrier and power allocation algorithm under interference and QoS constraints is proposed for cooperative OFDMA [12] based broadband wireless access networks. However, the problem is solved heuristically.

The authors formulated two different optimization problems to support two types of uplink flows and determined cross-layer trade-off between service rate and power consumption of users. Finally, they solved the problem using dual decomposition [13]. In this paper, we investigate the joint relay selection and resource allocation problem for the OFDMA-based system. We develop optimal schemes for relay selection, subcarrier assignment and power allocation with fixed relays, considering service differentiation. The resource allocation problem is formulated as the maximization of the total system throughput by satisfying individual users' QoS requirements subject to a total power constraint and solved it via a two level dual decomposition. We consider two types of users, Guaranteed Bit Rate (GBR) users and Aggregate Maximum Bit Rate (AMBR) users. The users are differentiated on the basis of minimum required data rate. GBR users have a specific rate requirement (e.g., real-time gaming) and AMBR users have a flexible service rate (e.g., best-effort and non-real-time service). We also present two suboptimal schemes based on equal power allocation, with power refinement to reduce computational complexity. Simulation results reveal that our proposed scheme significantly outperforms the traditional schemes in terms of both services support and QoS satisfaction.

The rest of the paper is organized as follows. Section II introduces the system model. The problem formulation and analytical framework for the optimal solution are presented in Section III. Optimal schemes based on equal power allocation with power optimal computational complexity is discussed are described in Section IV. Numerical results are shown in Section V, followed by concluding remarks in Section VI.

II. SYSTEM MODEL

A. User Model

In each cell, users are classified as either cell-center or cell-edge users depending on their current geographic locations. The boundary that separates the cell center and cell edge region, as shown in Fig.1, can be adjusted as a design parameter. Consider a single cell relay enhanced OFDMA-based uplink system with K users (UE) ($1 \leq k \leq K$) and N fixed relays ($1 \leq n \leq N$), where relays are shared by all users. The cell is divided into two ring shaped boundary regions and users are distributed between inner and outer boundaries. The reason is that the users located between inner boundary and outer boundary may require relays in most cases due to heavy blockage and long distance transmission [14]. Users located inside the inner boundaries are not considered because they do not require relays in most cases due to good channel condition since they are closer to the eNodeB. Resource allocation for these users may be done separately with simple algorithm.

The distance of the relays from the base station (eNodeB) is δR and the relay's angle relative to the base station is uniformly distributed in [0, 2δ], where R is the radius of the cell and δ is the distance factor

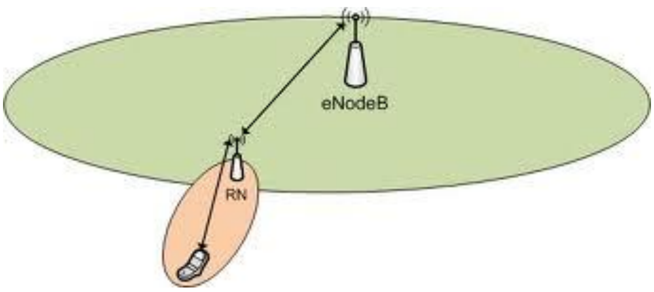

Fig .1 System model

The cell spectrum is divided into sub bands, each supported by a subcarrier the subcarriers are grouped into resource blocks (RBs). The broadband channel is assumed to be frequency-selective Rayleigh fading and the destination node (eNodeB) has perfect channel state information (CSI) of all links. There are two types of users: user class κ1, the Guaranteed Bit Rate (GBR) users, which have specific rate requirements (called rate constrained (RC) user) and the Aggregate Maximum Bit Rate (AMBR) users under the user class κ2, which have a flexible service rate requirements.

The minimum QoS requirement of the kth user is denoted by Qk. Based on QoS requirement; a user can transmit directly to the destination or transmit using cooperative communication. In cooperative scenario, the communication between the user and the eNodeB is carried out in two phases. In the first phase, the user transmits to the eNodeB which is overheard by the selected relay as well. In the second phase, the selected relay forwards to the eNodeB using the regenerate-and-forward cooperative protocol. The data received in both time slots are combined together by the eNodeB using maximal ratio combining (MRC). We assume that each user can have only y one relay, but each relay can support several users and a subcarrier is allocated to only one source and one relay. The transmit power of the kth user in the mth subcarrier is P_(s, k) ^m and the transmit power of the nth relay in the mth subcarrier is P_(r, n) ^m The noise variances of the source-to-relay (SR) links, relay-to-destination (RD) links and source-to-destination (SD) links per subcarrier are denoted by σ2S, R, σ2 R, D, σ2 S, D, respectively. The system model is presented in Fig. 1.The achievable rate in bits/sec/Hz for the regenerate-and forward scheme for the kth user in the mth subcarrier when the nth relay is selected, is given by

$$R^{m}_{k,n} = \begin{cases} \frac{1}{2}\min\left[\log_2\left(1+P^{m}_{s,k}\alpha^{m}_{k,n}\right)\right. \\ \log_2\left(1+P^{m}_{s,k}\alpha^{m}_{k,D}+P^{m}_{r,n}\alpha^{m}_{n,D}\right) & \text{cooperative mode} \\ \log_2\left(1+P^{m}_{s,k}\alpha^{m}_{k,D}\right) & \text{non cooperative mode} \end{cases} \quad \mathbf{(1)}$$

Where $\alpha^{m}_{k,D} = \frac{|h^{m}_{k,D}|^2}{\alpha^2_{k,D}}$,$\alpha^{m}_{k,n} = \frac{|h^{m}_{k,n}|^2}{\alpha^2_{k,n}}$ and $\alpha^{m}_{n,D} = \frac{|h^{m}_{n,D}|^2}{\alpha^2_{n,D}}$

And $\left|h^{m}_{k,D}\right|^2$, $\left|h^{m}_{k,n}\right|^2$, $\left|h^{m}_{n,D}\right|^2$ are the channel coefficients between the *k*th user and the destination, the *k*th user and the *n*th relay and the *n*th relay and the destination in the *m*thsub carrier, respectively.

Consider binary relay selection and subcarrier allocation characterized by the parameter$\rho^{m}_{k,n}$, where $\rho^{m}_{k,n}$ = 1 means that relay node n performs as a relay for user k in the mth subcarrier. Otherwise, it is equal to 0. We assume that each User can have only one relay, but each relay can support several users and a subcarrier is allocated to only one source and one relay, so that there is no interference between source14].

III. PROBLEM FORMULATION AND SOLUTION APPROACH

Our objective is to maximize the total system throughput subject to a set of constraints. The relay selection and subcarrier assignment constraints are as follows:

$$\sum_{k=1}^{K}\sum_{n=0}^{K}\rho^{m}_{k,n} = 1\, , \rho^{m}_{k,n}\epsilon\{0,1\}, \forall_m \quad \mathbf{(2)}$$

Where n = 0, it means user k utilize subcarrier m in non-cooperative mode. The total power allocated to the mth subcarrier of the kth user in both time slots is $P^{m}_{t,k} = P^{m}_{s,k} + P^{m}_{r,n}$[15] [16] and the total power constraint can be expressed as $\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{n=1}^{N}\rho^{m}_{k,n}P^{m}_{t,k} \leq P_T$

$$\mathbf{(3)}$$

WhereP_T is the sum of the power available for all users plus relays in the network. Although individual power constraints will lead more accurate power allocation, however, our goal is to maximize the total system throughput subject to a joint total power constraint, considering the simplicity of the problem formulations and lower computational complexity under the sum power constraint. The computational complexity is lower in the studied model since we only need to update one dual variable using subgradient method under the total power constraint compared to updating *K* +*N* dual variables simultaneously until all of them are converged when individual power constraints are used. Similar assumptions on the total power constraint are taken in previous studies [15], [16]–[17].

Maximization of the rate in using cooperative communication under total power constraint has advantageous only if $\alpha_{k,n}^m > \alpha_{k,D}^m$and $\alpha_{n,D}^m > \alpha_{k,D}^m$.[18] [19] additionally, in case of the cooperative mode, the rate will be maximized when the amount of received information at the relay and the destination are the same, i.e., $P_{s,k}^m\alpha_{s,k}^m = P_{s,k}^m\alpha_{k,D}^m + P_{r,n}^m\alpha_{n,D}^m$ Then the source power allocation is given by

$$\mathrm{P_{s,k}^m} = \begin{cases} \frac{\alpha_{n,D}^m}{\alpha_{k,n}^m+\alpha_{n,D}^m-\alpha_{k,D}^m}\mathrm{P_{t,k}^m}\ cooperative\ mode \\ \mathrm{P_{t,k}^m} \quad ,\text{non cooperative mode}\end{cases} \tag{4}$$

and the relay power allocation is given by

$$\mathrm{P_{s,k}^m} = \begin{cases} \frac{\alpha_{k,n}^m-\alpha_{k,D}^m}{\alpha_{k,n}^m+\alpha_{n,D}^m-\alpha_{k,D}^m}\mathrm{P_{t,k}^m}\ ,\text{cooperative mode} \\ 0,\text{non cooperative}\end{cases} \tag{5}$$

Substituting (4) and (5) into (1), [15] [18] the rate expression can be
Written as

$$\mathrm{R_{k,n}^m} = \begin{cases} \frac{1}{2}\left[\log_2\left(1+\mathrm{P_{t,k}^m}\alpha_{k,eq}^m\right)\right],\text{cooperative mode} \\ \log_2\left(1+\mathrm{P_{t,k}^m}\alpha_{k,D}^m\right),\text{non cooperative mode}\end{cases} \tag{6}$$

Where$\alpha_{k,eq}^m$ is the equivalent channel gain given by

$$\alpha_{k,eq}^m = \frac{\alpha_{k,n}^m\alpha_{n,D}^m}{\alpha_{k,n}^m+\alpha_{n,D}^m-\alpha_{k,D}^m} \tag{7}$$

$$R_k = \textstyle\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m \tag{8}$$

We formulate the joint resource allocation and relay selection problem subject to a minimum data rate *constraint* for each GBR users. The optimization problem can be formulated as

$$(P1)maximize$$

$$\rho,\mathrm{P_t}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m$$

Subject to

$c1{:}\rho_{k,n}^m \in \{0,1\},\forall k,m,n$

$$c2:\ \sum_{k=1}^{K}\sum_{n=0}^{M}\rho_{k,n}^m = 1,\forall m$$

$$c3:\ R_k \geq Q_k,\forall k \in\ k1$$

$$c4:\ \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m P_{t,k}^m \leq P_T$$

$$c5:\ P_{t,k}^m \geq 0,\forall k,m,n \tag{9}$$

Where constraints c1 and c2 represent the relay selection and Subcarrier allocation.

Constraint c3 applies minimum QoS requirements for the rate constrained users in terms of data rate requirement. Finally, the source and the relay power allocation are constrained by c4 and c5.

The optimization problem in (8) is a mixed integer programming (MIP) problem which is hard to solve. One challenging aspect of this problem in the context of OFDMA is the discrete nature of subcarrier assignment, which, when coupled with QoS constraint, makes the problem even harder to solve. Therefore, finding the optimal solution for this non-convex problem requires searching through all the possible user, relay and subcarrier allocations, which is prohibitively complex to employ in large system. However, to make the problem tractable, we relax the integer constraints $\rho_{k,n}^m$ to take any real value between 0 and 1 via time sharing condition which allows time sharing of each subcarrier. The duality gap of any optimization problem satisfying the time sharing condition is negligible as the number of subcarrier becomes sufficiently large [28]. Since our optimization problem obviously satisfies the time-sharing condition under distributed subcarrier mapping [8], it can be solved by using the dual method and the solution is asymptotically optimal [16].

A. Dual Problem

The Lagrangian function of problem () can be written as
L (ρ, Pt., λ, μ)
L $(\rho,P_{t,}\lambda,\mu)$

$$= \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m + \sum_{k\,\epsilon\,k1}\lambda_k(\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m$$

$$-Q_k) + \mu(P_T - \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{n=0}^{N}\rho_{k,n}^m P_{t,k}^m)$$

$$= \sum_{m=1}^{M}[\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m + \sum_{k\,\epsilon\,k1}\lambda_k\sum_{n=0}^{N}\rho_{k,n}^m R_{k,n}^m$$

$$-\mu\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^m P_{t,k}^m] - \sum_{k\,\epsilon\,k1}\lambda_k Q_k + \mu P_T \tag{10}$$

Where λ = $[\lambda_1,\lambda_2,\dots\dots\dots.\lambda_{k1}]^T$is the vector of the dual variables associated with the individual QoS constraints and μ is the dual variable for the power constraint. The Lagrangian dual function can therefore be written as

$$g(\lambda,\mu)=\begin{cases}\max L\,(\rho, P_t.\lambda,\mu\,) \\ \quad \rho, P_T \\ s.t.\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}\ +1\,,\forall\, m \\ 0\ \geq\ \rho_{k,n}^{m}\leq 1\,, P_{t,k}^{m}\ \geq 0.\end{cases}$$

(11)

Then the dual optimization problem is given by

$$\min_{\lambda,\mu\geq 0} g(\lambda,\mu)$$

(12)

The coupling between subcarriers via Lagrangian relaxation can be removed and (11) can be decomposed into M sub problems at each subcarrier, which can be solved independently given λ,μ with low complexity . The problem at each subcarrier is given by

$$\max_{\rho, P_t} L_m(\rho^m, P_t^m)$$

$$=\max_{\rho, P_T}\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}R_{k,n}^{m}+\sum_{k\,\epsilon\, k1}\lambda_k\sum_{n=0}^{N}\rho_{k,n}^{m}R_{k,n}^{m}$$
$$-\mu\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}R_{t,k}^{m}$$

$$s.t.\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}=1, 0\ \geq\rho_{k,n}^{m}\leq 1\,, P_{t,k}^{m}\ \geq 0,\forall k,n$$

Where ρ^m, P_t^m are the vectors of $\rho_{k,n}^m$,$P_{t,k}^m$ on the *m*thsubcarrier, respectively. The sub problem can be further decomposed through a second level primal decomposition. The decomposition hierarchy of the dual problem.

B. Optimal Power Allocation for a Given Relay Assignment And Subcarrier Allocation

Let subcarrier m be allocated to user k and relay n in a frame of transmission time and $\rho_{k,n}^m$ = 1. Then optimal power allocation over this subcarrier and relay assignment can be determined by solving the following problem

$$\max_{P_{t,k}^m} L_m, \forall k,n$$

(14)

$$s.t\ P_{t,k}^m\ \ \geq\ \ 0$$

Substituting (6) into (14) and differentiating L with respect to $P_{t,k}^m$us have

$$\frac{\partial L}{\partial P_{t,k}^m}=\frac{(1+\overline{\lambda_k})\alpha_{k,eq}^m}{2\ln(2)(1+P_{t,k}^m\alpha_{k,eq}^m)}-\mu$$

(15)

Where

$$\overline{\lambda_k}=\begin{cases}\lambda_k\,,\forall k\in k1 \\ 0, otherwise\end{cases}$$

Where$\overline{\lambda_k}$. $=\lambda_k$,$\forall k\in k1$ Applying the Karush-Kuhn-Tucker (KKT) condition, we can deduce the optimal power allocation as follows:

$$P_{t,k}^{m*}=\left[\frac{1+\overline{\lambda_k}}{2\mu\ln(2)}-\frac{1}{\alpha_{k,eq}^m}\right]^+$$

(16)

Where $|x|^+ = \max[x, 0]$.

C. Joint Optimal Relay Selection and Subcarrier Allocation

By eliminating the power variables in (14) and then substituting into (10), we have an alternative expression of the dual function as

$$g(\lambda,\mu)=\max_{\rho}\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}H_{k,n}^{m}(\lambda,\mu\,)$$

(17)

$$-\sum_{k\in k1}\lambda_k Q_k+\mu\,P_T$$

$$s.t.\sum_{k=1}^{K}\sum_{n=0}^{N}\rho_{k,n}^{m}=1,\forall m, 0\geq\rho_{k,n}^{m}\leq 1$$

Where the function $H_{k,n}^m(\lambda,\mu)$ is defined as follows

$$H_{k,n}^m=\frac{1}{2}(1+\overline{\lambda_k})\left[log_2\left(1+P_{t,k}^{m*}\alpha_{k,eq}^m\right)\right]-\mu P_{t,k}^{m*}$$

(18)

An intuitive explanation for each term in (18) is as follows. The first term can be viewed as the rate obtained by selecting subcarrier *m* by user *k* and relay *n* and the second term is the price for the power consumption. Therefore, $H_{k,n}^m$ can be interpreted as the gain of transmitting over subcarrier *m* by user *k* and relay *n* and H = $[H_{k,n}^m]$ can be represented as a *K* **N* profit matrix at each subcarrier *m*. In other words, the profit matrix **H** is different for different value of *m*. The objective function in (17) can be maximized by picking exactly one element of matrix **H** for each subcarrier so that the sum of profit is as large as possible. Finally, optimal relay selection and subcarrier allocation should be the one having the maximum value of$H_{k,n}^m(\lambda,\mu)$ in (18) and is given by

$$\rho_{k,n}^m=\begin{cases}1,(n^*,k^*)=\arg\max_{n,k}H_{k,n}^m \\ 0, otherwise\end{cases}$$

(19)

subcarrier using both transmission modes is computed using (16). Then, these power allocation values are used in (18) to compute$H_{k,n}^m$. After that, for each subcarrier, the user and relay pair is determined using (19) that gives the largest$H_{k,n}^m$. Noncooperative mode is the case that no relay is selected, i.e., n = 0.In the operation, first, the power allocation for each

D. Variable Update

Since a dual function is always convex by definition, subgradient method can be used to minimize *g* (*λ*, *μ*). Dual variables *λ* and *μ* are updated in parallel as follows

$$\lambda_k(t+1) = \left[\lambda_k(t) + \eta(t)(Q_k - \sum_{n=0}^{N}\sum_{m=1}^{M} \rho_{k,n}^{m}(t) R_{k,n}^{m}(t))\right]^{+}$$

$$\mu(t+1) = \left[\mu(t) + \theta(t)(\sum_{k=0}^{K}\sum_{m=1}^{M}\sum_{n=0}^{N} \rho_{k,n}^{m}(t) R_{k,n}^{m}(t) - P_T)\right]^{+} \quad \textbf{(20)}$$

Whereη (t) and θ (t) are diminishing step sizes and t is the iteration index. The subgradient method above is guaranteed To converge to the optimal dual variables if the step sizes are Chosen following the diminishing step size policy [29]. Based on the mathematical formulations and derivations, the optimal relay selection, subcarrier assignment and power allocation can be computed algorithmically.

IV. OPTIMAL SCHEMES AND COMPLEXITY ANALYSIS

The computational complexity of the proposed optimal scheme may still be too high for practical implementation. In this section, we present EPA schemes which have lower computational cost compared to the tradition optimal one.

A .Equal Power Allocation (EPA) Scheme

In this scheme, we determine relay selection and subcarrier allocation assuming that the power is equally distributed over all subcarriers. First, relay selection and subcarrier allocation are performed for the GBR users in two steps considering that AMBR users are absent.

In step 1, to ensure fairness among the users, we select the user whose current achievable rate is the farthest away from its minimum rate requirement. In step 2, for the selected user, we choose the subcarrier and relay that maximize the transmission rates$R_{k,n}^{m}$, rather than the metrics $H_{k,n}^{m}$ defined in (18). Steps 1 and 2 are repeated until all users are satisfied or the numbers of unassigned subcarriers are zero. Then the remaining subcarriers and power are distributed among the AMBR users to maximize the sum rate. In this case, to exploit multi-user diversity, subcarriers are allocated to the user and relay pair who can utilize the channel the best. Let S_k be the set of subcarriers assigned to user k and A be the set of unassigned subcarriers. The pseudo code of the EPA
Scheme is presented

B. complexity analysis

The computational complexity of the proposed optimal scheme is mainly determined by the complexity of solving The dual problem the total number of computations needed To perform relay selection is K $(N+1)$ and M allocations are Required for all subcarriers. Therefore, the complexity at each iteration is O (MKN). The complexity of the subgradient method is polynomial in the number of dual variables. With the total power constraint, there are κ_1+1 dual variables and the overall complexity is O $(|\kappa_1|^2 MKN)$. The complexity of the whole scheme is polynomial, which is significantly lower than employing the exhaustive search solution to the master the complexity of the EPA scheme can be analysed as follows. The complexity of allocating subcarriers to the GBR users is $O(|\kappa_1|MN)$ and the complexity of allocating the remaining subcarriers to the AMBR users is $O(|\kappa_2|(M - |\kappa_1|)N)$. So, the overall complexity of the EPA scheme is O $(|\kappa_1|MN)$ + O $(|\kappa_2|$ $(M - |\kappa_1|)$ $N)$.

V. NUMERICAL RESULTS

To evaluate the performance of our scheme, numerical results are generated using a MATLAB simulation. The simulation parameters are given in Table I. Relay selection is performed per RB since RB is the smallest resource unit for the LTE networks. The relay locations are varied to show the effect of relay locations on the performance. Here, we only consider random variations of the relay distance from the eNodeB as the first step. However, relay placement can be modelled as another optimization problem which is not studied in this paper. The UE locations are randomly generated and uniformly distributed between 0.5 Km to 1 Km from the eNodeB. Half of the users in the system are assumed to be GBR and the other half are AMBR users. The GBR users are selected randomly from the total set of users. These GBR users have different rate requirements based on the applications. We allocate different applications to different users arbitrarily, and they are fixed for the whole simulation. Multipath Rayleigh fading with exponential power delay profile based on ITU pedestrian B model [2] is considered for small scale fading model. The channels for different users in each subcarrier are assumed to be independent. Then the effective channel gain over an RB is deduced from the subcarrier granularity. The 3GPP LTE path loss models with log-normal shadowing of an 8dB standard deviation are assumed.

TABLE I SIMULATION PARAMETERS

Name of the Parameters	Value
Cell radius	1 KM
Relay locations from eNodeB	0.5 KM
UE locations	0.5 to 1 KM
Channel model	Multipath Rayleigh fading
Path loss model	3GPP LTE
Total system bandwidth	5 MHz
Total number of RB	24
Total number of subscribers	288
Number of UEs	24
Number of relays	2, 4, 6, and 8
Total power available at UE	23 dBm
Total power available at relay	30 dBm
Noise power spectral density	-174 dBm/Hz
Path loss exponent	3.76

The system parameters are given in Table I. Having the simulation scenarios and all the system parameters, the optimal relay selection, power allocation and subcarrier assignments are evaluated using Algorithm. The step size for λ and μ is set to 0.01 divided by $\sqrt{IterationNumber}$.Relay selection is performed per RB, since RB is the smallest resource unit for the LTE network. The simulation scenario (user locations, selection of the GBR users and the assignment of the applications to the users) is repeated 100 times to get a fair result. The multipath channel components are repeated over 1000 times. The optimization problem considered in this work may be infeasible due to the rate requirements constraint. This may happen if the channel condition is very bad (low SNR) and/or the available resources are limited to support the minimum rate requirements of the GBR users. In the simulation, we allocate resources as much as possible for the GBR users on those infeasible cases and also consider them when we calculate the average spectral efficiency. Those situations have been further verified and handled by introducing the user satisfaction index (SI). The user satisfaction index (SI) [30] is calculated as SI $= \frac{1}{k}\sum_{k=1}^{K} SI_k\,, where\ SI_k = \min(\frac{R_k}{Q_k}, 1)$ .SI is less than 1 means there are some cases which are infeasible and the minimum rate requirements for some users are not satisfied.

Fig. 2 shows the average throughput per user in bits/sec/Hz for the optimal scheme, and traditional optimal schemes as a function of the number of relays. The EPA scheme provides slightly lower throughput compared to the optimal scheme, because the optimal scheme always allocates subcarriers by considering the channel condition and minimum rate requirement. So, some users have very high rate since most of the subcarriers are allocated to those users, whereas others have very low rate because very few or no subcarriers are allocated to them.The optimal scheme considers both minimum rate requirement as well as channel condition, and distributes the subcarriers to the users based on their minimum rate requirement. So, when we average over the total number of channel realizations, the average throughput is higher for the optimal scheme but it violates fairness which is also evident in Fig.2. However, the performance gap for the optimal scheme reduces with an increase in the number of relays. It is noted that all optimal schemes provide lower throughput compared to the traditional optimal scheme.

The EPA scheme with power refinement performs well although they have lower computational complexity compared to the optimal one. The EPA scheme has higher rates compared to the optimal scheme. This is due to the power refinement and subcarrier adjustment used in the EPA scheme. The average throughput for the GBR users for all schemes as a function of the number of relays is shown in Fig.3.The traditional scheme provides the lowest throughput since it consider both users' minimum rate requirements and channel condition .The optimal scheme has the highest throughput in all cases. However, all optimal schemes exhibit performance close to each other with increase in number of relays increases.

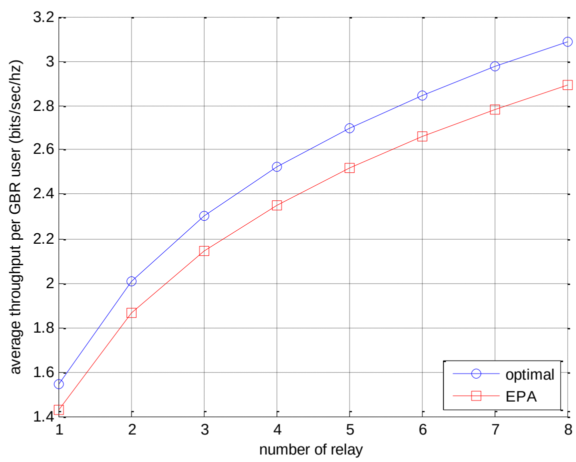

Fig .2 Average throughputs for GBR user as a function of number of relays,$\partial = 0.5$

The reason is that all optimal schemes first allocate subcarriers and power to the GBR users, and when all GBR users are satisfied, the remaining subcarriers and power are then allocated to the AMBR users. So, the reverse characteristic is observed in case of AMBR users for all schemes except the optimal scheme, as shown in Fig.3. Since the AMBR users have no minimum rate requirements, the traditional optimal scheme provides the highest throughput. Fig 4 provides the comparison of throughput for GBR and AMBR user with relay distance of ∂=0.5

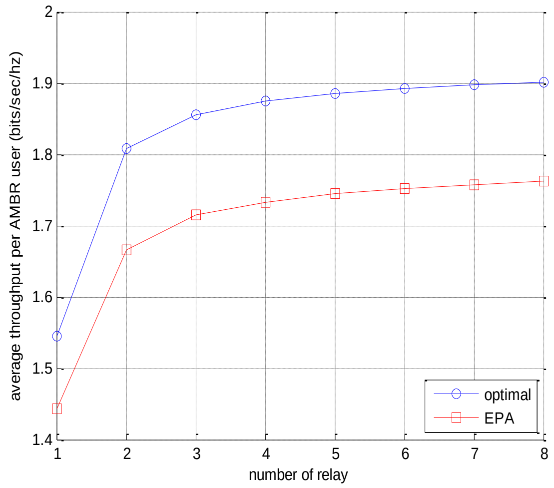

Fig.3. Average throughput for AMBR user as a function of number of relays, ∂=0.5

The optimal scheme still provides moderate performance. The average rate obtained by each user for the optimal scheme, EPA scheme. Since all optimal schemes have almost the same performance in case of GBR users, we only show the EPA scheme which has good overall throughput with lower computational complexity, i.e., EPA scheme. In this illustrative example, there are four GBR users with different minimum rate requirements .The minimum rate required for users 2 and 8 are 4 bits/sec/Hz and 2 bits/sec/Hz for users 4 and 6.

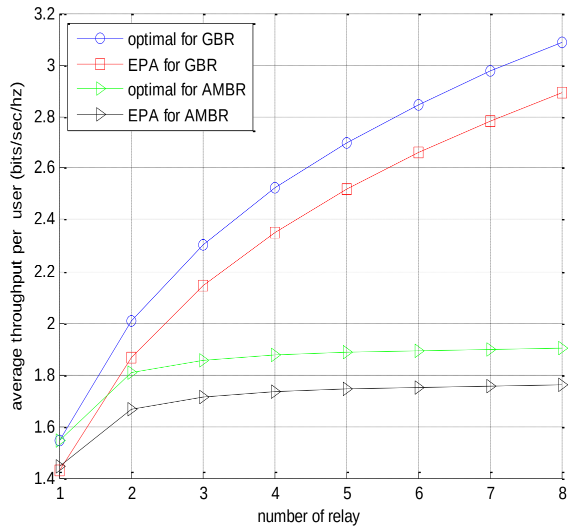

Fig .4 Average throughput for GBR and AMBR user as a function of number of relays, ∂=0.5 comparison

The remaining users have no minimum rate requirements. But both the optimal and EPA schemes satisfy the minimum rate requirement for all GBR users and support all other AMBR users. So, it can be concluded that our proposed EPA scheme with power refinement provide not only fairness and user satisfaction but also support heterogeneous demand as well. This will be more evident via satisfaction. Index (SI) in Fig.5...SI = 1 means all users rate requirements are satisfied. The SI is much higher for the optimal scheme and EPA scheme compared with the unconstrained scheme. It is also observed that all users are satisfied in case of the optimal scheme and EPA scheme when the number of relays increases. But all users are not satisfied even for 8 relays in case of the unconstrained scheme due to the same reason as stated above. The EPA scheme exhibits slightly higher SI than the optimal scheme. Because the EPA scheme first allocates resources to the GBR users, and when all GBR users are satisfied, the remaining resources are then allocated to the AMBR users Fig. 6 shows the total system throughput as a function of the number of users, with the number of relays as a parameter. The total throughput increases with the number of users or relays. This gives insight into the scalability of our schemes.

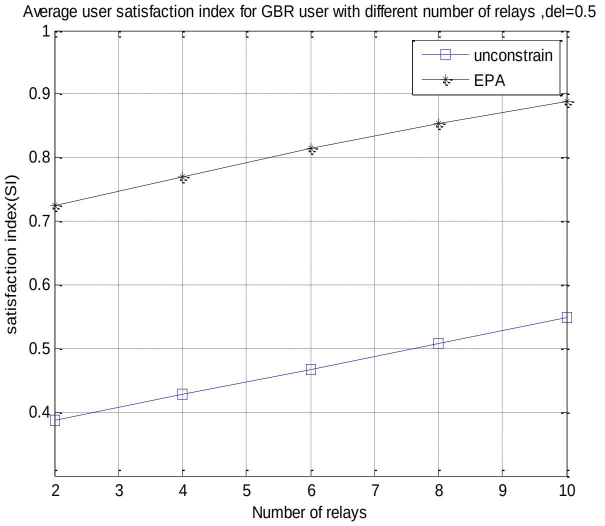

Fig 5. Average user satisfaction index for GBR user with different number of relays, $\partial = 0.5$

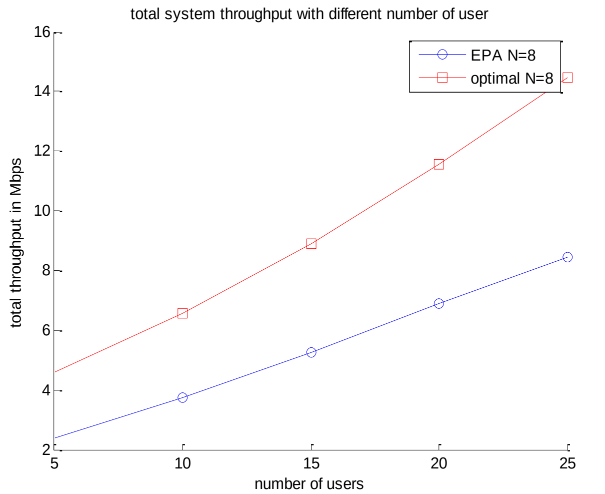

Fig.6. total system throughput with different number of user, $\partial = 0.4$

VI. CONCLUSION

In this paper, relay selection and resource allocation in a multi-user cooperative OFDMA-based system that simultaneously supports GBR and AMBR traffic have been investigated. A QoS aware optimal joint relay selection, power allocation and subcarrier assignment scheme under a total power constraint has been proposed. A joint optimization problem has been formulated for relay selection and resource allocation with the objective of maximizing the system throughput by satisfying the individual users' QoS requirements. By relaxing the integer constraints, the joint optimization problem has been transformed into a convex optimization problem, which is solved by means of a two level dual decomposition approach. The computational complexity has been finally reduced via the introduction of EPA schemes. Numerical results have demonstrated that our schemes support heterogeneous services while satisfy QoS requirements of each user. The polynomial complexity of the optimal scheme facilitates the implementation of this optimization at the base station. However, the EPA schemes can be implemented with significantly reduced computational complexity while sacrificing some system throughput. For the future work, we will investigate the performance of our schemes in the presence of imperfect CSI at the base station.

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S.TAMILSELVAN received his BE in Electronics and communication Engineering from Madras University in 1999 and M.Tech in Electronics and Communication Engineering from the Pondicherry Engineering College in 2001. He received his PhD degree in the area of Wireless Communication from Pondicherry University during the year 2011. Currently, he is working as an Assistant Professor in the Department of ECE, Pondicherry Engineering College, India. His current research interests are in wireless communication systems, mobile and distributed computing.

GAJALAKSHMI.R obtained her B.Tech degree (2011) in Electronics and Communication Engineering from Sri Manakula vinayakar engineering college affiliated to Pondicherry University, Pondicherry. Currently, she is pursuing M.Tech in the Department of Electronics and communication engineering, Pondicherry engineering college, Pondicherry University, Pondicherry, INDIA.

D. PRABAKAR received the B.Tech degree (2007) in the Department of Electronics and Communication Engineering from Arunai Engineering College affiliated to Anna University and M.Tech degree (2009) in the Department of Electronics and Communication Engineering from Pondicherry Engineering College affiliated to Pondicherry University, Pondicherry, INDIA. He is currently working as Assistant Professor in the Dept. of Electronics and Communication Engineering, PRIST University, Pondicherry, India. His research interests include Wireless Communication and Wireless Networks.