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# ROBUST RADIO RESOURCE ALLOCATION IN LTE NETWORKS BY CHANNEL AND RELAY ASSIGNMENT

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**Abstract**

The radio resource allocation in wireless communication is analysed in this paper. Pair of users communicates each other through multiple two way relays in orthogonal frequency division multiplexing transmission systems. The total throughput is maximized by relay selection, channel and relay assignment, subcarrier pairing and subcarrier allocation by prim's algorithm. The graphical theory approach has used to solve the problem optimally in polynomial time. The evaluation of the network total throughput with respect to transmit power node and the number of relay nodes are analysed through simulation. In this work, the improvement in sum rate with optimum carrier assignment using proposed algorithm is demonstrated against the classical work.

Keywords:.Orthogonal frequency division multiplexing (OFDM), Relay, Sub-carrier pairing, Prim's algorithm, Graph theory, Throughput.

## 1. Introduction

The requirement of ubiquitous networks and booming volume of multimedia application traffics demand energy consumption and optimal utilization of resources. To meet these demands, various wireless communication techniques have been developed. One of the promising techniques is the cooperative relay networks. Cooperative wireless relay networks have the inherent ability, to exploit various diversity to reduce channel fading and they naturally extend coverage. For the users, the cooperative communication is offering wide range of data services and helps in achieving the required diversity gains. Cooperative communication explores the wireless channel broadcasting nature and users cooperation to improve the system performance.

In a single relay cooperative networks, joint optimization of channel pairing, channel user assignment and power allocation maximizes the weighted sum-rate has been discussed in detail in the past [1]. In a dual hop cooperative network, the capacity bounds with opportunistic single relay selection is addressed [2]. The sub-carrier usage along with bit loading has been analysed with power control for cooperative communications [3]. Direct dual hop with green resource allocation schemes with reduced computational complexity has also been proposed. In the green resource allocation, mixed downlink (DL) and uplink (UL) relaying schemes with block diagonalization to jointly allocate transmission power, sub-channel and phase is studied [4]. The resource allocation in two-way relay, especially in estimation of downlinks transmission delay in power transmission using network coding is also analysed [5]. The network coding technique is also used in orthogonal frequency division multiplexing (OFDM) based multiple access channels for resource allocation in a multi-dimensional way [6]. In resource allocation using relays, to achieve a better performance sub-carrier pairing is an important issue and optimal utilization of sub-carrier is necessary to reduce co-channel and adjacent relay channel interference. The sub-carrier pairing with joint optimization of power, relay selection, channel and relay assignment has been done in the past. In resource allocation using OFDM based network to maximize the overall throughput among multiple pair of two users, optimal coordination between relay and sub-carrier assignment is also demonstrated [7].

To maximize the throughput in OFDM based two hop relay, lot of research has already been undertaken. One such joint power constraint to maximize the link relay rate is given in [8]. As said earlier, relaying schemes uses the channel state information to maximize the performance. Since the accurate channel state information (CSI) is hardly available, the relay design with channel state information impacts the resource allocation. One such a scheme in multi-relay Orthogonal Frequency Multiple Access (OFDMA) systems, imperfect CSI to jointly optimize link selection and power allocation has been analysed [9]. If the CSI is not perfect, the system suffers from various forms of interference. The sum-rate maximization in interference limited systems for optimal resource allocation using Decode and Forward (DF) cooperation strategies is also discussed [10]. Whether the CSI degrades the system performance or not, the idea of cooperation in resource allocation using relays used to reduce the computational complexity besides improving sum-rate. With minimal computational complexity, the multi-relay systems in OFDM were studied using joint power allocation [11].

Time division duplex systems for OFDMA have been proposed to optimize the subcarrier pairing [12]. A more heuristic method of sub-carrier pairing with separate power allocation is analysed with three - node, two - way relaying in OFDM systems using water filling algorithm [13]. Combinatorial optimization problem of joint resource assignment, relay selection and bidirectional transmission scheme selection to maximize the total product of backlog and rate (back-pressure principle) has been formulated. A graph based framework is transformed into a maximum weighted clique problem (MWCP) and also transformed in to a 3-D assignment problem (3DAP). A hybrid ant colony optimization (ACO) algorithm is used to solve 3DAP [14]. From the recent research, it has been found that the joint optimizing sub-carrier pairing and number of relays for sum-rate maximization is an important issue and our intuition is to provide the solution with Prim's algorithm.

In this paper, the sum-rate is maximized by using Prim's algorithm and achieved the higher sum-rate than the recent works.

## 2. System Model for Resource Allocation Problem

In this work, an OFDM-based wireless network is considered as in Fig. 1. This system has $K$ number of user pairs (source in set one and two) and $R$ number of relays, where the sources exchange information between them through the relays. And direct communications between any two sources are not permitted to avoid shadowing effect. The source and relay are communicated in a half-duplex mode. The relay operates in two-way relaying with constant gain. We also postulate central processor to control all the communication in the network by non-transparent centralized scheduling mode of relay allocation method [15]. So, the relays are amplified and forward the information provided by the source. The wireless fading environment with large scale path loss and shadowing and small scale frequency selective fading is modelled. We consider the perfect channel estimation in the network where, the link have different independent fading channel and the network operate in slow fading environment. The circular symmetric complex Gaussian random variables are considered as additive white noises for all nodes independently and the transmit power of the all subcarriers are uniformly distributed.

Consider $N = \{1, 2, \ldots,\}$ as the set of subcarriers, $R = \{1, 2, \ldots,\}$ as the set of relays, and $S = \{1, 2, \ldots,\}$ as the set of user pairs. $S_{k,1}$ and $S_{k,2}$ are the pair of sources in the $k^{th}$ set user pair. In the network, half duplex communication is considered between sources and relay node. The $k$ pairs of user communicate between them through $r^{th}$ relay (one of the $R$ relay) as shown in Fig. 1. The communication between pair of user happened in two phases. Phase one labelled as multiple access (MAC), where $S_{k,1}$ user transmitter will transmit the signal to relay $r$ by non-overlapping subcarriers to avoid inter pair interference. The subcarrier in the phase one is denoted as $m$. The intra-pair interference will be consider as back-propagated self-interference and cancelled after two-way relaying. Phase two termed as broadcast (BC) phase, relay $r$ will broadcast the received signal to $2K$ user after amplification of signal. To avoid inter relay interference, each relay will use non overlapping subcarriers. The subcarrier in the phase two is denoted as $n$. To avoid inter carrier interference, each pair of subcarrier assigned to one relay and each relay will use more than one pair of subcarrier. We assign subcarrier m with user $S_{k,1}$ to transmit the signal to relay $r$ and subcarrier $n$ with $r$ to transmit the amplified signal to user $S_{k,2}$. So, the achievable sum rate of user pair $k$ over subcarrier pair $(m,n)$ through relay $r$ can be written as

$$\begin{aligned} R_{k,r,m,n} &= \frac{1}{2}\log_2\left(1+\frac{\gamma_{k_1,r,m}\gamma_{r,k_2 n}}{1+\gamma_{r,k_2,n}+\gamma_{k_1,r,m}+\gamma_{k_2,r,m}}\right) \\ &+\frac{1}{2}\log_2\left(1+\frac{\gamma_{k_2,r,m}\gamma_{r,k_1,n}}{1+\gamma_{r,k_1,n}+\gamma_{k_1,r,m}+\gamma_{k_2,r,m}}\right) \end{aligned} \tag{1}$$

where $\gamma_{i,j,n}$ denotes the instantaneous signal-to-noise ratio (SNR) from $i^{th}$ node to $j^{th}$ node over $n^{th}$ subcarrier. All the nodes in the system are assumed to have the unit noise variance. For subcarrier assignment, a set of binary variables $\rho_{k,r,m,n} \in \{0,1\}$ introduced for all user pair *k*, relay *r*, subcarrier *m* and *n*, where $\rho_{k,r,m,n} = 1$ means that subcarrier *m* in the first phase is paired with subcarrier *n* and in the second phase assisted by relay *r* for user pair *k*, and $\rho_{k,r,m,n} = 0$, otherwise. As assumed above, each subcarrier can be assigned to one user pair and one relay, in the first and second phases, respectively to avoid interference. Therefore, $\{\rho_{k,r,m,n}\}$ must satisfy the following constraints:

$$\sum_{k\in K}\sum_{r\in R}\sum_{n\in N}\rho_{k,r,m,n} \le 1, \forall_m \in N \tag{2}$$

$$\sum_{k\in K}\sum_{r\in R}\sum_{m\in N}\rho_{k,r,m,n} \le 1, \forall_n \in N \tag{3}$$

The system total throughput will be maximized by optimally pairing subcarriers in the two phases and selecting the best relays and the best paired subcarriers for each user pair. From Eqs. (1), (2) and (3) the mathematical formula for relay assignment and subcarrier pairing can be written as.

$$\max \sum_{k\in K}\sum_{r\in M}\sum_{m\in N}\sum_{n\in N} R_{k,r,m,n}\rho_{k,r,m,n} \tag{4}$$

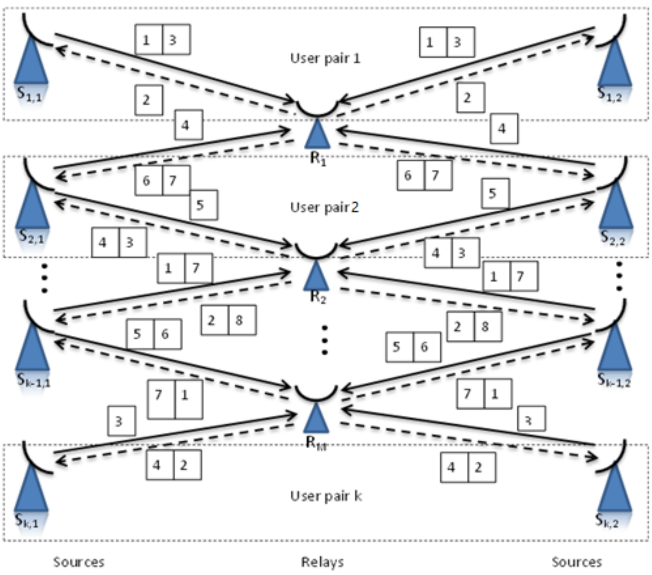


**Fig. 1. System Model with $S_{k,1}$ and $S_{k,2}$ are $k^{th}$ user pair and $R_M$ the $r^{th}$ relay.**

## 2.1. A graph-based optimal approach

The above problem in Eq. (4) is an optimization algorithm to select relay and subcarrier pair that find the optimal solution with long search operation. When *K*, *R* and *N* increase, the complexity of the solution also increases exponential and it is not fit to find optimal solution. So, we modify the objective function in Eq. (4) to weighted sum of all user rates without change in optimum solution using graph based algorithm. The proposed optimum path algorithm finds the maximum weighted subcarrier pair (*m*,*n*) as follows.

$$R(m,n) = \max_{k \in K, r \in R} R_{k,r,m,n} \tag{5}$$

The associated user pair and relay node can take the maximum in Eq. (5) for each subcarrier pair (*m*,*n*) are denoted as *u* and *v* respectively. Consequently, we can transform the original problem in Eq. (4) to the following simplified problem in Eq. (6) without loss of optimality:

$$\begin{aligned} \max \quad & \sum_{m \in N} \sum_{n \in N} R(m,n) \rho_{u,v,m,n} \\ s.t. \quad & \sum_{n \in N} \rho_{u,v,m,n} \le 1, \ \forall_m \in N, \\ & \sum_{m \in N} \rho_{u,v,m,n} \le 1, \ \forall_n \in N. \end{aligned} \tag{6}$$

As per the discussion stated above, it implies that the simplified equation in Eq. (6) is equivalent to a maximum weighted bipartite matching (MWBM) problem.

## Bipartite Graph

The nodes in the bipartite graph are divided into two disjoint sets. In a set of edges, connect corresponding node of both the sets. The balanced bipartite graph has both sets with same cardinality. A matching is a set of mutually disjoint edges, i.e., any two edges do not share a common node. A perfect matching occurs when t every node in the graph is matched as in Fig. 2. Construct a balanced bipartite graph *G=(V1×V2,E,W),* where the two set of vertices, *V1=[X1,X2,...Xm]* and *V2=[Y1,Y2,....Yn]*, are the set of subcarriers *N* in the MAC phase and the BC phase, respectively, as in Fig. 2. *E* is the set of edges that connect all possible pairs of vertices in the two set. N is shared in each phase, thus $|V1| = |V2| = |N| = N$ and $|E| = N^2$, where |.| is cardinality of a set. *W* is the weighting function such that $W: E \to \mathbb{R}^{+}$.

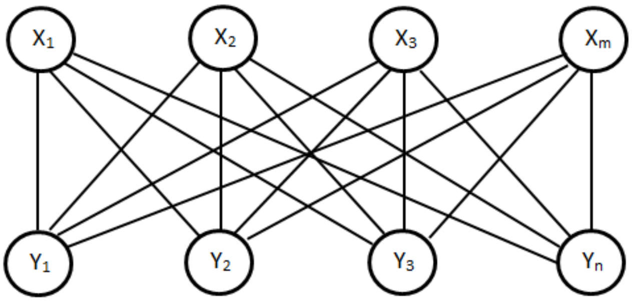


**Fig. 2. Bipartite graph, where X is set of MAC subcarrier and Y is the set of BC subcarrier.**

More specifically, each edge is assigned a weight, representing the maximum achievable rate over the matched two vertices, namely,

$$W_{(m,n)} = R(m,n) \quad (7)$$

where $R(m,n)$ is defined in Eq. (5). From Eq. (6) the total complexity is calculated as O(KRN$^2$) and weight of all edges are calculated.

The following equivalences are found according to the above graph method: (i) A subcarrier pair in the MAC and BC phases are matched as a pair of vertices, (ii) a matching implies no violating the exclusive subcarrier assignment in each phase defined in Eqs. (2) and (3), and (iii) the optimal user pair and relay for each possible subcarrier pair has been found by weight of each edge in E. As a result, the modified Prim's algorithm of subcarrier-pairing based subcarrier assignment and relay selection in multi-relay multi-pair two-way relaying networks for the total throughput maximization is equivalent to finding a perfect matching $F \subseteq E$ in $G$ to achieve maximum sum weights of *F*. This MWBM problem is stated in Eq. (8).

$$\max_{F \subseteq E} \sum_{(m,n) \in F} W_{(m,n)} \quad (8)$$

which is NP-complete and equivalent to problem in Eq. (5).

The important aspect of the Graph based algorithm is the mapping from the original problem Eq. (4) to the simplified problem Eq. (6) and then to the MWBM problem Eq. (8) without loss of optimality. After the mapping is done, the classic Hungarian algorithm can be adopted to solve Eq. (8) optimally with the computational complexity $O(N^3)$. By combining the about mentioned complexity of the weighting process, the total complexity of graph based greedy algorithm is O (KRN$^2$+N$^3$), which is polynomial.

## 3. Modified Prim's Algorithm

Let *G= (V,E)* where *V* is the set of nodes and *E* is the set of edges (No. of subcarrier)

$V1, V2 \in V$ , $u \subset V1$ and $v \subset V2$

The edge cost $e_m \subset E$

Step1. Choose an element *u* from set *V1*

Step2. Choose an element *v* from set *V2*

Step3. Choose minimum cost edge $e_m$ from set *E*,

Step4. If the cost of edge $e_m$ is less than minimum cost, then minimum cost is cost of edge $e_m$, Repeat step 2 to step 4 till all nodes in *V2* are checked.

Step5. Repeat step 1 to step 4 till all nodes in *V1* are checked.

Step6. Assign node *v* and node *u* which satisfy the minimum edge criterion defined in step 4.

The modified prim's algorithm for the bipartite graph based optimization problem whose computational complexity decreases from greedy algorithm [7], it is easy to pair the subcarrier between sources to destination and suitable relay.

## 4. Simulation and Results

Simulation is carried out with uniform distribution for the selection of source nodes and relay nodes. The path loss model is adopted in [7], where the path loss exponent is set to 4 and the standard deviation of log-normal shadowing is set to 5.8 dB. The small-scale fading is modelled by multi-path Rayleigh fading process, where the power delay profile is exponentially decaying with maximum delay spread of 5 μs and maximum Doppler spread of 5 Hz. A total of 2000 independent channel realizations were generated, each associated with a different node locations. The number of subcarriers is $N$ = 64. All sources have the same maximum power constraints, with all relays satisfying the relay power and user pair power $P_r = P_{k1} + 3dB = P_{k2} + 3dB$ (per-subcarrier) for all $r$ and $k$. As a performance benchmark, the fixed subcarrier pairing scheme is considered. As in [7], signals transmitted by the user pair on one subcarrier in the MAC phase is forwarded on the same subcarrier by a relay in the BC phase, i.e., $m = n$, rather than seeking the optimal subcarrier pairing. Then the problem reduces in selecting the optimal user pair and relay for each subcarrier to achieve throughput maximization, which can be optimally solved by the Greedy algorithm and proposed Prims algorithm. Each subcarrier m shall be assigned to the user pair and the relay that satisfy $(u,v) = \arg \max_{k\in K, r\in M} R_{k,r,m,n}$. Then the results of fixed subcarrier pairing, Greedy algorithm and Prims algorithm are analysed.

The overall complexity of the fixed subcarrier paring scheme is O(KRN) and graph based Greedy algorithm has O(KRN$^2$ + N$^3$). The simulation result reveals that the complexity of the proposed graph-based scheme is O(KRN$^2$), which is higher than the benchmark scheme and less as that of the Greedy algorithm.

The source, destination and relay nodes are placed randomly but follow uniform distribution in two-dimensional plane as shown in Fig. 3. Figure 4 illustrates the total throughput with five user pairs and four relays in the network. The graph indicates that the proposed optimal channel and relay assignment with optimal subcarrier pairing achieves 20% improvement in total throughput over the scheme with fixed subcarrier pairing and 10% over the classical work. Table.1 lists out the performance improvement comparison of proposed Prim's algorithm with Greedy algorithm and fixed subcarrier pairing algorithm.

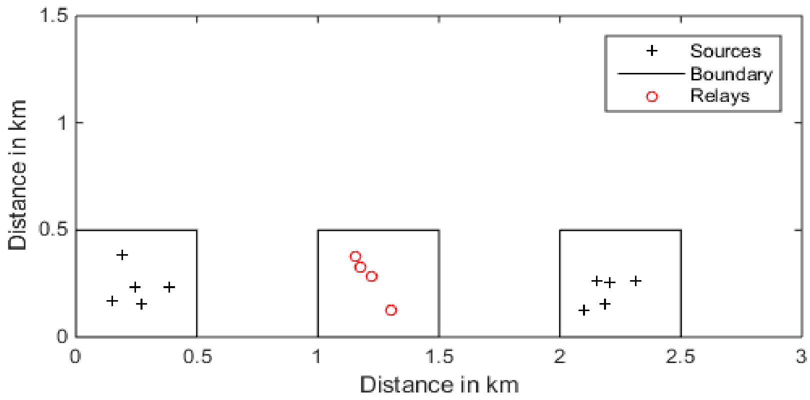


**Fig. 3. Two dimension plane of user and relay**

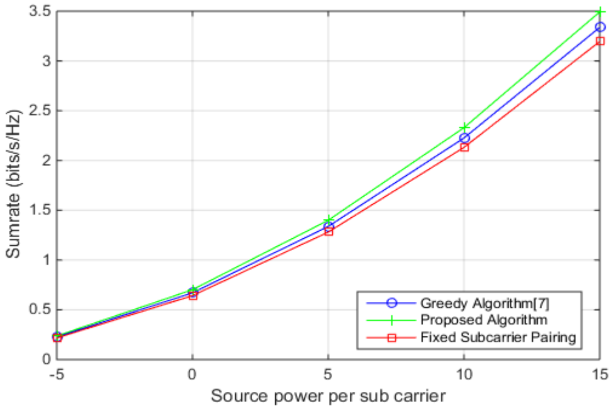


**Fig. 4. Performance comparison of the proposed Prim's algorithm with Greedy algorithm [7] and benchmark.**

**Table. 1. Performance of sum-rate**

| S. No | Source power/sub carrier | Sumrate (bits/s/Hz) | | |
|---|---|---|---|---|
| | | Proposed Prim's Algorithm | Greedy Algorithm | Fixed Subcarrier Pairing |
| **1.** | -5 | 0.2342 | 0.2239 | 0.2144 |
| **2.** | 0 | 0.6993 | 0.6683 | 0.6399 |
| **3.** | 5 | 1.3970 | 1.3350 | 1.2782 |
| **4.** | 10 | 2.3272 | 2.2239 | 2.1293 |
| **5.** | 15 | 3.4900 | 3.3350 | 3.1931 |

Figure 5 shows the throughput performance versus the number of relays with five user pairs and $P_{K1}$ = 10 dB. It is found that from proposed Prim's algorithm, relay selection diversity increases by multiple relays in the system. However, the gain variation is significantly less as the number of relays *R* increases. This is attained with respect to the capacity scaling of relay selection which is *log log R* [2].

Figure 6 the number of subcarrier pairing N=16, 32 and 64 are considered with adaptive subcarrier pairing. The sum rate performance of the network is better when the number of subcarrier paring is lesser.

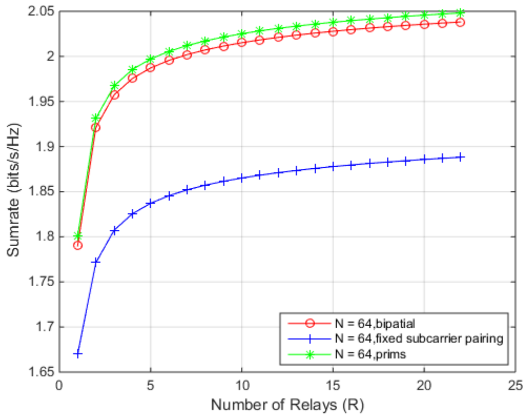


**Fig. 5. Effects of the number of relays, where *N* = 64, *K* = 5, and $P_{k1}$ = 10 dB.**

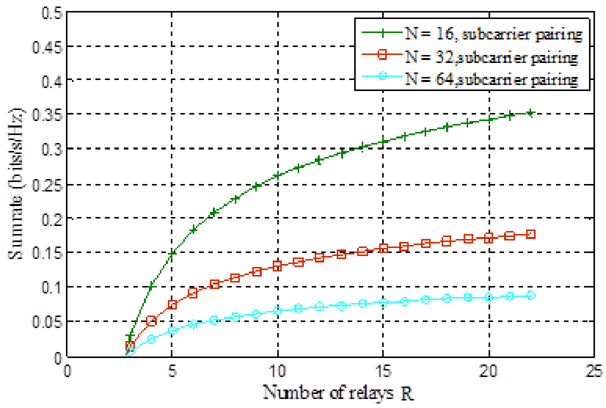


**Fig. 6. Effects of number of relays, where different number of subcarrier pairing.**

## 5. Conclusions

The work concludes that the subcarrier-pairing based subcarrier assignment and relay selection for LTE networks using Prim's algorithm was optimal. The problem was designed as a combinatorial optimization problem and NP-complete. We proposed an optimization algorithm for bipartite graph to solve the problem optimally in polynomial time. The work assumed the amplify-and-forward based non-regenerative relay strategy. The work can extend to 128 subcarriers and more. The total throughput improves by 10 % from the conventional method.

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