Optimal Channel and Relay Assignment in OFDM-based System using AF and DF Relay Strategies

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Abstract : ***We consider a 2-hop wireless relay network where multiple user pairs conduct bidirectional communication via multiple relays based on orthogonal frequency division multiplexing transmission (OFDM). Channel optimization and relay assignment, including sub-carrier pairing, sub-carrier allocation as well as relay selection, for total throughput maximization is formulated for different relay strategies. Using a graph theoretical approach, we solve the problem optimally in polynomial time by transforming it into a maximum weighted bipartite matching (MWBM) problem. Simulations studies are carried out to evaluate the network total throughput versus transmit power per node for AF and DF and the number of relay nodes for different number of subcarriers.***

Keywords: Two-way relaying, orthogonal frequency division multiplexing (OFDM), subcarrier pairing and maximum weighted bipartite matching (MWBM)

1. Introduction

A relay is an electrically operated switch which is used in wireless networks for various purposes like coverage extension, power saving and throughput enhancement. There are various factors which can be considered to enable high data rates in a relay based system like selecting the right number of relays and subcarriers. This coupled with Orthogonal-frequency-division multiplexing (OFDM) can be used to employ efficient relaying systems with improved efficiency. Relay strategies can be classified as amplify-and-forward (AF) and decode-and-forward (DF). In AF, the relay simply amplifies the source signal linearly whereas, in DF, the relay fully decodes, re-encodes and retransmits the source code word. Subcarrier is assigned from source to relay link and relay to destination link. Relay assignment is investigated thoroughly in [1] and [2]. However, both the papers assume the same subcarrier for both the links in the relay based system. From [3] and [4], it is inferred that a better performance can be achieved if both the links assume different subcarriers which can be optimally paired.

OFDM is employed for transmission over time dispersive channels in the two-way relay network (TWRN), where two source terminals exchange their information through a relay terminal using AF and DF relaying schemes. We propose a two-phase protocol for the channel estimation, which is compatible with the two-phase data transmission scheme. In the first phase, the two source terminals send their individual training sequences concurrently to the relay nodes. In order to avoid inter-pair interference, each user pair occupies non-overlapping subcarriers. The intra-pair interference will be treated as back-propagated self-interference and cancelled perfectly after two-way relaying. In the second phase, the signal is modified based on the relay strategy selected and broadcasted to the destinations.

Compared with the existing works in [1]–[7], our problem involves two major technical challenges. The first one is the subcarrier pairing and assignment. Though the optimal subcarrier pairing has been found for one-way relaying such as [3]–[5], only heuristic subcarrier pairing methods are available for two-way relaying [6], [7]. In addition, the problem is more involved in the multi-user scenario since subcarriers should not only be carefully paired for each two-way link but also be assigned adaptively for different users. The second challenge lies in the fact that subcarrier pairing and relay selection are tightly coupled, i.e. different relay selections lead to different subcarrier pairing and assignment, and vice versa.

We formulate the joint optimization problem of sub carrier pairing based subcarrier assignment and relay selection for multiple two-way users as a combinatorial optimization problem. We then adopt a graph based approach and establish the equivalence between the proposed problem and a maximum weighted bipartite matching (MWBM) problem. Then the problem is solved by the corresponding graph based algorithm optimally in polynomial time. The remainder of the paper is organized as follows. Section II introduces the system model. Problem formulation is detailed in Section III. Section IV provides simulations to verify the effectiveness of the algorithm. Finally, we conclude the paper in Section V.

2. System Model

We consider an OFDM-based wireless network with K pairs of users and M relays as shown in Fig. 1, where each user pair exchanges information via the relays. Each node operates in a half-duplex mode. We model the wireless fading environment by large-scale path loss and shadowing, along with small-scale frequency selective fading. We assume that the channels between different links experience independent fading and the network operates in slow fading environment, so that channel estimation is perfect. In relay-assisted wireless networks such as IEEE 802.16j, the relay nodes are usually fixed and hence the network channel state information can be reliably gathered and utilized at one of the relays. The additive white noises at all nodes are assumed to be independent circular symmetric complex Gaussian random variables. We further assume that the direct communication link between the two users in each pair is neglected due to the shadowing effects. This assumption is commonly used in the literature (e.g., [6], [8]–[11]). In this work we do not pursue power allocation for simplicity. It is known that power allocation can bring significant improvement in relay networks when all source and relay nodes are subject to a total power constraint [3]. However, the gain brought by power allocation is very limited in OFDM-based relay networks if each transmitting node is subject to an individual peak power constraint [3], [5], [6]. In the considered system model, all nodes are subject to their own individual peak power constraints and, therefore, the transmit power is assumed to be uniformly distributed across all subcarriers.

1) System Model

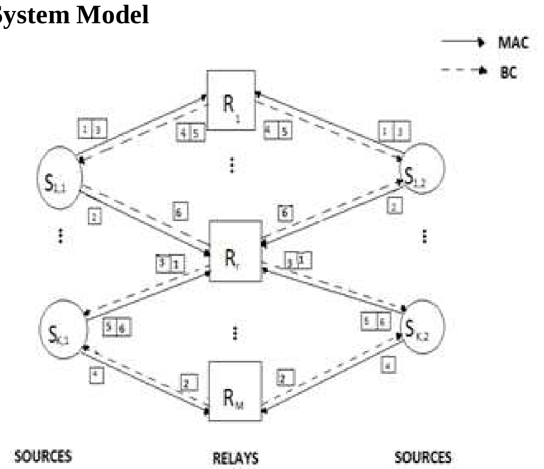

Figure 1: System model, where $S_{k,1}$ and $S_{k,2}$ denote the two sources of the k-th user pair. The grids denote the subcarrier indexes

3. Bipartite Graph

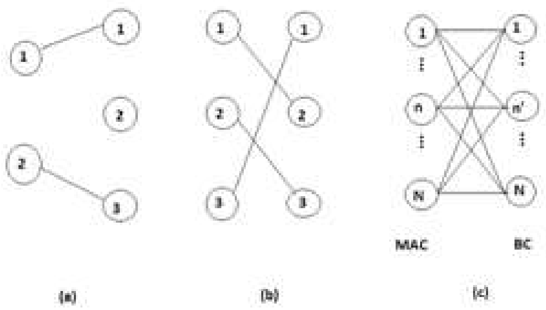

Figure 2: Bipartite graphs. (a) An example of a matching. (b) An example of a perfect matching. (c) The proposed bipartite graph.

4. Problem Formulation

Let $\mathcal{N}=\{1, 2, \cdots,\}$ denote the set of subcarriers, $\mathcal{M}=\{1, 2, \cdots,\}$ denote the set of relays, and $\mathcal{K}=\{1, 2, \cdots, K\}$ denote the set of user pairs. Denote $k1$ and $k2$ as the two sources in the k-th user pair, respectively. The achievable sum-rate of user pair k over sub carrier pair $(n,')$ with the assistance of relay can be expressed as **:**

$$R_{k,r}^{n,n'} = \frac{1}{2}C\left(\frac{\gamma_{k_1r}^{n}\gamma_{rk_2}^{n'}}{1+\gamma_{rk_2}^{n'}+\gamma_{k_1r}^{n}+\gamma_{k_2r}^{n}}\right)+\frac{1}{2}C\left(\frac{\gamma_{k_2r}^{n}\gamma_{rk_1}^{n'}}{1+\gamma_{rk_1}^{n'}+\gamma_{k_1r}^{n}+\gamma_{k_2r}^{n}}\right)$$

For AF, (1)

$$R_{k,r}^{n,n'} = \min\left\{C\left(\gamma_{k_1r}^{n}\right), C\left(\gamma_{rk_2}^{n'}\right)\right\} + \min\left\{C\left(\gamma_{k_2r}^{n}\right), C\left(\gamma_{rk_1}^{n'}\right)\right\}$$

For DF, (2)

Where $C(x)=\log_2(1+x)$, γ_{ij}^{n} Denotes the instantaneous signal-to-noise ratio(SNR) from node i to node j over the subcarrier n. Optimally pairing subcarriers in the two phases and selecting the best relays and paired subcarriers for each user pair can be mathematically formulated as (P1):

P1: (3)

$$\max \sum_{k\in K}\sum_{r\in M}\sum_{n\in N}\sum_{n'\in N} R_{k,r}^{n,n'}\,\rho_{k,r}^{n,n'}$$

Problem **P1** is a combinatorial optimization problem. In order to reduce the complexity of problem P1, we assume,

$$R(n,n') = \max_{k\in K, r\in M} R_{k,r}^{n,n'}$$

(4)

The original problem P1 is transformed into P2 without the loss of optimality

P2: (5)

$$\max \sum_{n\in N}\sum_{n'\in N} R(n,n')\,\rho_{k^*,r^*}^{n,n'} \quad (5)$$

$$\sum_{n'\in N} \rho_{k^*,r^*}^{n,n'} \le 1, \forall n \in N$$

$$\sum_{n\in N} \rho_{k^*,r^*}^{n,n'} \le 1, \forall n' \in N$$

This simplified **P2** is a MWBM problem. Now, in the bipartite graph each edge is assigned a weight, representing the maximum achievable rate over the matched two vertices. Namely,

$$W_{(n,n')} = R(n,n') \quad (6)$$

Subcarrier matching so as to maximize the sum-weight is given by,

P3:

$$\max_{F^* \subseteq \varepsilon} \sum_{(n,n') \in F^*} W_{(n,n')} \quad (7)$$

This is the final MWBM problem.

5. Simulation Results

A two-dimensional plane of node locations where source nodes and relay nodes are distributed uniformly has been considered. We adopt the path loss model in [13]. All the sources have same maximum power constraints; hence, all the relays have same maximum power constraints.

As a performance benchmark we considered 32 subcarriers in both the phases. Fig. 3 illustrates the total throughput when there are K=5 user pairs, M=4 relays and with the number of subcarriers as 32 and 16 in the network .we observed that the proposed system achieves 10-15% improvement in total throughput over the scheme with 32 subcarriers.

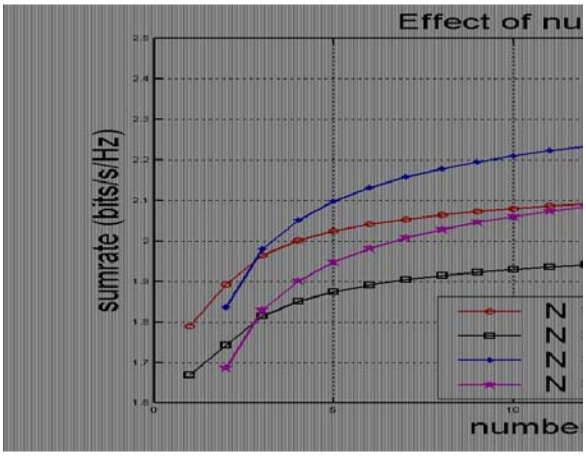

Figure 3: Performance comparision by changing the number of subcarrier form 32 to 16

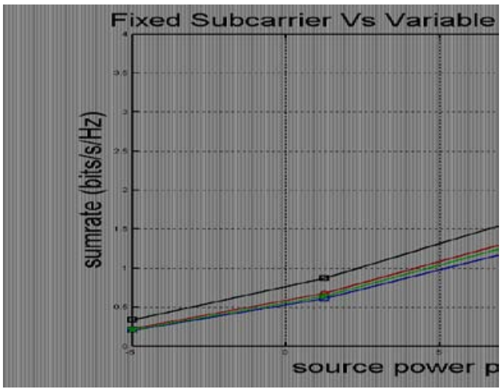

Figure 4: Performance Comparison for AF And DF Relay Strategies

Fig.4 shows the throughput performance for two different types of relay strategy of which one is amplify-and –forward and the other is decode-and –forward relay strategy. It has been inferred that the data rate has been increased when decode-and –forward relay strategy is used compared to that of amplify-and –forward strategy in case of both fixed and variable subcarrier pairing.

6. Conclusions

The joint optimization of subcarrier-pairing based subcarrier assignment and relay selection for multi-relay multi-pair two-way relay OFDM networks was investigated. The problem was formulated as a combinatorial optimization problem solved by bipartite matching approach. Performance comparison by reducing the number of subcarriers from 32 to 16 has been done by assuming amplify-and-forward relay strategy. Throughput comparison for amplify-and-forward and decode-and-forward relay strategies is carried out. The similar problem based on more advanced regenerative two-way relay strategies can be considered in the future work. The fading environment and path loss model also can be changed and the results can be compared.

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