Semi-Distributed Resource Allocation Based on Multihop Equilibrium for Cellular OFDM-Relay Networks

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SUMMARY A semi-distributed resource allocation scheme based on multihop equilibrium is proposed for OFDM-relay networks. This method aims to reduce the amount of feedback information from the relay nodes (RNs). Moreover, it utilizes radio resource by striking an efficient balance between the capacities of the BS-RN link and RN-MS link. Simulation results show that the proposed semi-distributed scheme achieves good performances in terms of throughputs and fraction of satisfied users.

key words: OFDM-relay, semi-distributed, multihop equilibrium

1. Introduction

With the rapid development of wireless communication techniques, B3G/4G wireless systems are required to provide high throughput, broad coverage and high utilization [1]. Orthogonal frequency division multiplex (OFDM) is adopted as B3G/4G allocating policy since it is an efficient way to combat frequency selective channels. Besides, relay technique is essential to provide reliable link in order to overcome shadowing effect. Therefore, OFDM-relay system attracts much attention currently.

In the multi-cell OFDM-relay environment, one of the major issues is how to allocate the subcarriers and the power of base station (BS) and relay node (RN) efficiently. There is a total of three types of allocation schemes in cellular relaying networks, namely centralized, distributed and semi-distributed strategy. [2] proposes a centralized scheduling scheme for OFDMA/TDD relaying networks; however, the mobile stations (MSs) and RNs are required to feedback the full channel state information (CSI) of all links. Thus, the centralized method may be infeasible due to the un-affordable complexity. In [3], distributed relay selection strategies are proposed with limited feedback information. Unfortunately, distributed resource allocation may lead to unwilling intra-cell co-channel interference. Besides, a novel alternative, namely the semi-distributed (also known as hierarchical) resource allocation scheme is proposed with partial decision making in BS and RNs [4].

In this paper, we focus on designing an effective semi-distributed resource allocation scheme for cellular OFDM-relay networks with decode-and-forward (DF) relaying. The proposed scheme in [4] needs the RN feedback the allocation decisions to the BS; moreover, it does not take the multihop equilibrium (ME) for relaying users into account, which is the main feature of DF relaying networks. Differing from [4], our method aims to reduce the amount of feedback information from the RNS, and utilize radio resource by striking an efficient balance between the capacities of the BS-RN link and RN-MS link. We also believe that the RNSs with “semi-distributed” management functions are feasible and suitable for the requirement of long term evolution-advanced (LTE-A) system.

The rest of the paper is organized as follows. Section 2 describes the system model and the related works. In Sect. 3, we present a novel semi-distributed resource allocation scheme in detail. The complexity analysis is presented in Sect. 4. The simulation results are deployed to validate the performance in Sect. 5. Finally, we conclude the paper in Sect. 6.

2. System Model and Related Work

We consider a downlink resource allocation strategy in a OFDM-relay cellular network with M co-channel cells. The BS is placed at the center of each cell, and L fixed RNSs are placed uniformly and located at 2/3 radius away from the BS. There are totally K MSs randomly located within the network, comprising Kd direct users and Kr relay users. The entire system bandwidth B is divided into N orthogonal sub-channels. Half-duplex DF relaying is adopted, and the time slot is divided into 2 equal subslots in order to support the multihop transmission. Let pm(i, n) denote the transmission power on the ith (i = 1, 2) subslot of the nth (n = 1, · · · , N) subchannel in cell m (m = 1, · · · , M). Then the power constraints are

\[ \sum_{n \in N} p^m_S(i, n) \leq P_{max}^S, \sum_{n \in N} p^m_R(2, n) \leq P_{max}^R, \]

where \( P_{max}^S \) and \( P_{max}^R \) are the maximum transmission power of BS and RN, respectively. Let \( d_{nk}^m \) denote the achievable rate for the kth user on the nth subchannel of the mth cell, and \( R_{nk}^m \) is the minimum data rate requirement for user k. Define \( d_{nk}^m \) is the assignment of the nth subchannel to user k of cell m, which can be expressed as

\[ d_{nk}^m = \begin{cases} 1 & \text{if subcarrier } n \text{ is assigned to user } k \\ 0 & \text{otherwise} \end{cases} \]

The optimization target is to maximize throughput and satisfaction ratio. In [5], we propose downlink centralized scheduling schemes, and a distributed resource allocation
method is presented in [6]. Based on our previous work, a semi-distributed method is proposed.

3. Proposed Semi-Distributed Method

Our approach to optimization is based on joint sub-channel allocation (SA) and power allocation (PA) step by step. That is, assign subchannel when PA is definite, and allocate power resource if SA is determined. Its procedure is as follows:

- **Step 1 CSI feedback (f.b.) to access service node**
  The BS requests the CSI feedback of BS-MS link and BS-RN link, and the RN requests the CSI feedback of RN-MS link.

- **Step 2 Average data rate f.b. for RN-MS link**
  The RN estimates the average achievable rate for each MS connected to it, according to the CSI of RN-MS link. Then, RN sends the average achievable rate information (partial information) to BS.

- **Step 3 Phase-I allocation at BS**
  Based on the CSI feedback of RNs and direct users, the BS scheduler distributes resources to RNs (all the RNs can be regarded as a user) and direct users for the 1st subslot transmission to all the MSs except RN-MS link according to maximize throughput criterion with minimum data rate requirement.

- **Step 4 Phase-II pre-allocation at BS**
  By utilizing the average achievable rate information from RNs, BS calculates a required amount of subchannels for each relay user from the data amount estimator. Thus, BS picks the estimated amount and allocates the subchannels to the RN following step 3.

- **Step 5 Phase-III allocation at RN**
  The RN scheduler obtains the received amount of data in the 1st subslot for each relay user from its data memory. Then, RN dispenses the pre-allocated subchannels to relay users for the 2nd subslot transmission.

The proposed semi-distributed method is shown in Fig. 1. Suppose the input information of BS for Phase I includes the data rate requirement vector \( \mathbf{R}^m = [R^m_1, R^m_2, \ldots, R^m_N] \) and the estimated capacity vector \( \mathbf{c}^m_n = [c^m_{n,1}, \ldots, c^m_{n,K}] \), where

\[
e_{n,k} = \begin{cases} \text{sum rate of 2 subslots} & k = k_d \\ \text{data rate of 1st subslot} & k = k_r \end{cases}
\]  

The uniform power allocation is assumed in (1). Thus, the Phase I can be expressed as Table 1 in detail.

**Phase II** aims to strike a balance between the two hops’ throughput. Due to the partial information feedback, we devise a rough pre-allocation method where the BS estimates a required number of subchannels for each RN according to its users’ average capacities over all the subchannels in the 2nd hop.

| 1 | Initialization: set \( n = 1 \), \( PR_{h_1}^m = c^m_{n,k} \), \( \forall k \). |
| 2 | while \( n \leq N \) |
| 2-1 | Find the \( k \) with the largest \( PR_{h_1}^m \), and set \( a^m_{n,k} = 1 \). |
| 2-2 | Update \( d^m_{h_1,k} = R^m_k - \sum_{j=1}^{n-1} a^m_{j,k} c^m_{j,k} \). |
| 2-3 | Update \( PR_{h_1,k}^m = c^m_{n,k} (d^m_{h_1,k} / R^m_k) \), \( \forall k \). |
| 2-4 | If \( PR_{h_1,k}^m = 0 \), set \( PR_{h_1,k}^m = c^m_{n,k} \). |
| 2-5 | and \( n = n + 1 \). |
| 3 | Water-filling PA on allocated subchannels |
| 3-1 | Estimate the power constraint for \( k \), i.e., \( P_{max} \parallel \mathbf{N}_k \parallel / \parallel \mathbf{N} \parallel \), where \( \parallel \mathbf{x} \parallel \) means to obtain element number of \( x \). |
| 3-2 | Allocate the power according to |
| 3-3 | \( p^m_k(1,i,n) = \min \left\{ \mu_k c_{n,k}^{m} / a^m_{n,k} - \frac{a^m_{n,k}}{R^m_k}, 0 \right\} \), |
| 3-4 | where \( \mu_k \) is the Lagrange multiplier, and |
| 3-5 | \( Q^m_{h}(i,n) = SINR^m_{h}(i,n) / p^m_k(i,n) \). |

In **Phase III**, the target of subchannel allocation problem is to minimize the gap between data rate of the 1st and the 2nd hop for each relay user \( k_r \), that is

\[
\min \left| R_{h_1}^m(1) - \sum_{n=1}^{N_c} a_{n,k_r} c_{n,k_r}^m (2,n) \right|
\]  

where \( R_{h_1}^m(1) \) is the data rate of the first hop of user \( k_r \). (2) can be regarded as ME mechanism, which has been addressed and proved in [5].

The procedure of **Phase III** is similar with **Phase I**, except for the difference in step 2-2), that the iterative step is \( d^m_{h_1+1,k} = R^m_k (1) - \sum_{n=1}^{N_c} a^m_{n,k_r} c_{n,k_r}^m (2,n) \) and the power allocation of RN is shown as (3), where (3) is the result of solving (2) with ME mechanism.

\[
p^m_{h}(2,n) = \left( \frac{a_{n,k_r} c_{n,k_r}^m (2,n)}{\prod_{n=1}^{N_c} Q^m_{h}(i,n)} \right)^{\frac{1}{N_c}}
\]  

4. Complexity Analysis

To evaluate the algorithm complexity, we compare the semi-distributed scheme with the centralized strategy and the distributed one, which is shown in Table 2.

Note that the RN-MS feedback is only \( K_r \) in our scheme, which is different from that of [4], i.e., \( LN \). The inequality \( K_r < LN \) is valid in practical system.
### Table 2  Comparisons of different schemes.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>RN-MS f.b.</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized</td>
<td>$NK_r$</td>
<td>$o(2KN)^2$</td>
</tr>
<tr>
<td>Distributed</td>
<td>0</td>
<td>$o(KN)^2 + o(K_r N_r)^2$</td>
</tr>
<tr>
<td>Semi-distributed</td>
<td>$K_r$</td>
<td>$o(KN)^2 + o(K_r) + o(K_r N_r)^2$</td>
</tr>
</tbody>
</table>

### Table 3  Minimum rate requirement settings.

<table>
<thead>
<tr>
<th>Rate</th>
<th>200 kbps</th>
<th>1 Mbps</th>
<th>2 Mbps</th>
<th>14 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>70%</td>
<td>20%</td>
<td>7%</td>
<td>3%</td>
</tr>
</tbody>
</table>

![Average rate of relay users vs. system load.](image1)

![Satisfaction ratio of all users vs. system load.](image2)

## 5. Performance Evaluation

We set up a 7-cell simulation scenario, and adopt a 6-path Rayleigh model with 631.4 ns r.m.s delay spread. Assume $P_{S}^{\max}=20$ W, $P_{R}^{\max}=2.5$ W, $N=128$, $B=2$ MHz, $L=6$, $K$ is from 30 to 50, and the noise power is $-143$ dBm. The $R_k$ settings are shown in Table 3.

The average throughput of relay users is shown in Fig. 2, and Fig. 3 depicts the fraction of satisfied users versus the system load. The proposed method outperforms the distributed strategy in both relay users’ average data rate and satisfaction ratio of users. Moreover, it achieves very close performances compared with the centralized scheme. Compared with the method in [4], the average throughput of relay users can be enhanced by 11% due to the ME mechanism, and fraction of satisfied users can be improved by 3%. Taking the algorithm complexity into account, the proposed semi-distributed scheme is a good tradeoff between complexity and performances in terms of throughput and fraction of satisfied user for future LTE-A system.

## 6. Conclusion

In this paper, we presented a semi-distributed resource allocation scheme based on multihop equilibrium. It not only reduces the feedback from RN-MS link, but also decreases the complexity compared with the centralized method. Simulation results indicate that the relaying system achieves good performances in terms of throughputs and fraction of satisfied users by applying the proposed semi-distributed method with multihop equilibrium mechanism.

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### References


