AMC-based resource allocation in adaptive frequency reused OFDMA-relay networks

CHEN Yu (✉), FANG Xu-ming

School of Information Science and Technology, Southwest Jiaotong University, Chengdu 610031, China

Abstract

In orthogonal frequency division multiple access (OFDMA) relay system, for supporting relay transmission, the base station (BS)-the relay station (RS) link must consume an extra part of resource, which may result in serious resource shortage. In order to improve resource utilization, this paper proposes a dynamic resource allocation scheme in adaptive frequency reused OFDMA-relay system based on adaptive modulation and coding (AMC) technology. In this scheme, relay nodes have two independent antennas and operate in decode-and-forward (DF) and full-duplex mode. Then the BS and RSs share the same subcarriers by spatial multiplexing by two independent antennas. The resource allocation problem is formulated for system downlink throughput maximization. Since the optimal solution couldn’t be obtained easily, a sub-optimal algorithm is proposed. The adaptive frequency reused algorithm with two independent antennas RS improves the system throughput about 24.3% compared with the orthogonal frequency allocation with single-antenna model, and increases the system throughput 10.4% compared with adaptive frequency reused algorithms with single-antenna RS. It is proved that both of the RS with two-antenna model and adaptive frequency reused scheme can improve the system throughput significantly.

Keywords AMC, resource allocation, adaptive frequency reuse, OFDMA, relay

1 Introduction

In OFDMA system, the user diversity could be implemented by carefully select the proper frequencies. Recently some papers have proposed the dynamic subcarrier allocation, bit allocation and power distribution solutions to increase the cell throughput and improve the spectral efficiency [1–3]. In next generation communication, the relay technology is introduced in 802.16j, 802.16m and LTE-advanced to provide broader signal coverage, higher data transmission rate, and faster mobility. However, in relay system, the BS-RS link must consume an extra part of resources, and it may result in more resource shortage. Many previous researches focused on the orthogonal resources (in time or frequency) allocated to the users in the cell of the relay system [4]. They divide the bandwidth into many fixed frequency bands, and then different RS and BS are allocated different orthogonal resources by a resource management policy. Ref. [5] proposed the optimal algorithm in half-duplex relay system with the sub-channel allocated to achieve maximum system throughput. To save the resources used in BS-RS link, the work on relay-based network assume that RS can transmit and receive simultaneously in the same subcarriers, i.e. work on full-duplex mode [6]. However there are many limitations in radio implementation preclude the terminals from this operation. Therefore there lack of sufficient studies about adaptive-reuse subcarrier allocation between BS and RS based AMC relay system.

In this paper, suppose BS and RSs share the same frequency through AMC and spatial multiplexing by using the DF relay with two independent antennas. The target is to maximize the system throughput of a broadband cellular OFDMA system with the adaptive frequency reuse between BS and RSs. Because the optimal algorithm is a non-linear optimization problem with integer variables, this paper proposes a sub-optimal algorithm. The sub-optimal algorithm uses the characteristic of the AMC-based system, which can
tolerate some interference. Then the subcarriers are adaptively chosen to the BS or an RS or both, through channel state information (CSI) and the condition of the interference. And the subcarriers assignments for BS and RS are separated, that simplify the non-linear optimization with integer variables.

2 System model

This paper considers an AMC-based multiuser dual-hop downlink system with minimum data rate constraints for each MS. The system has $K$ active mobile stations (MSs), $M$ RSs and a single BS, as shown in Fig. 1. It is denoted that the first hop is the BS-MS link or BS-RS link, and the second hop is the RS-MS link. It is assumed that the wireless channel between each pair of transmitting and receiving nodes is frequency selective, and OFDMA is employed for data communication to divide the channel into a set of $N$ orthogonal subcarriers with flat channel responses and additive white Gaussian noises (AWGN). Furthermore, all MSs and the BS in the system are equipped with a single antenna. All RSs use the model with two antennas, an omni-directional antenna for the RS-MS links and a directional antenna for the BS-RS link, i.e., for receiving DL data from the BS. This detailed model is described in Ref. [7].

AMC can be independently applied to each link in the system because of using DF RS. The selected modulation and coding scheme (MCS) might be different for both hops. Therefore the subcarrier can select MCS according to SINR denoted as $\gamma$, and the rate of the MCS can be simply expressed as

$$f(\gamma) = \max \{c | c \leq \log(1 + \gamma) \}, c \in \{c_0, c_1, ..., c_w\}$$

where $c_0, c_1, ..., c_w$ are the corresponding rates of MCSs, which are all constant. As an example, $w = 7$ and different MCSs are listed in Table 1 [8], the bit error rate (BER) is $10^{-4}$.

<table>
<thead>
<tr>
<th>Coding rate and</th>
<th>Spectral</th>
<th>SINR at $10^{-4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>modulation level</td>
<td>efficiency (bit s$^{-1}$ Hz$^{-1}$)</td>
<td>BER (dB)</td>
</tr>
<tr>
<td>QPSK 1/2</td>
<td>1.00</td>
<td>4.65</td>
</tr>
<tr>
<td>QPSK 3/4</td>
<td>1.50</td>
<td>7.45</td>
</tr>
<tr>
<td>16-QAM 1/2</td>
<td>2.00</td>
<td>10.93</td>
</tr>
<tr>
<td>16-QAM 3/4</td>
<td>3.00</td>
<td>14.02</td>
</tr>
<tr>
<td>64-QAM 2/3</td>
<td>4.00</td>
<td>18.50</td>
</tr>
<tr>
<td>64-QAM 3/4</td>
<td>4.50</td>
<td>19.88</td>
</tr>
<tr>
<td>64-QAM 7/8</td>
<td>5.25</td>
<td>21.94</td>
</tr>
</tbody>
</table>

We also assume that the two antennas are independent of each other, and the directional antenna’s beam is very narrow. Therefore the RS-MS link doesn’t interfere with the BS-RS link when the two links use the same resources simultaneously. The subcarriers in BS-RS link can be reused in the RS-MS link. The rate under AMC is discrete, and the link with AMC can tolerate some interference. For this reason some subcarriers used in BS-MS link can be also used in RS-MS link if the interference is acceptable. Thus the BS and RS can use the same subcarrier, i.e. the BS and the RS reuse the adaptive frequency band. However sharing a subcarrier by BS or different RS is not allowed where the BS serves as the central planner for the cell that controls the resource allocation of all users and all relays with all CSI (channel state information). Additionally, the average transmit power of each subcarrier of both BS and RS, on the other hand, is kept constant. The average power of subcarrier transmitted from BS is $P_{\text{BS}}$, and the one transmitted from RS is $P_{\text{RS}}$. Next section will focus on the downlink resource allocation for the system, which maximizes the system throughput.

3 Problem formulation

In this paper, $R$ denotes the minimum required rate of users. For each subcarrier of index $n$, $\rho_{k,n}$ is defined to indicate whether the $n$th subcarrier is allocated to the BS-the $k$th MS link or BS-RS link, and $q_{n,k,s}$ indicates whether the $n$th subcarrier is allocated to the $m$th RS—the $k$th MS link. $A_{n,k}$ denotes the SINR of the link between BS and the $k$th MS. $B_{n,k,s}$ denotes the SINR of the link between the $m$th RS and the $k$th MS. $C_{n,k,s}$ denotes the SINR of the link between BS and the $m$th RS. Since the transmission in relay system includes both direct transmission and relayed transmission, it needs to define subcarrier assignment indexes to calculate achievable rate of user $k$ for distinguishing direct transmission from relayed transmission. Assignment indexes $\alpha_{k}$ and $\beta_{k}$ are defined as...
\[\alpha_k = \begin{cases} 1; & \text{user } k \text{ choose direct transmission} \\ 0; & \text{otherwise} \end{cases}\]

\[\beta_k = \begin{cases} 1; & \text{user } k \text{ choose relayed transmission} \\ 0; & \text{otherwise} \end{cases}\]

where, for each subcarrier, either \(\alpha_k = 1\) or \(\beta_k = 1\), directly or relayed transmitted. In addition if the user chooses direct transmission, the rate of user \(k\) is denoted as \(r_k^d\). If the user \(k\) chooses relayed transmission, and the RSs are with DF model, the rate of user \(k\) or relayed transmitted. In addition if the user chooses direct transmission, the rate of user \(k\) is denoted as \(r_k^r\). \(r_k^d\) and \(r_k^r\) can be written as

\[r_k^d = \sum_{n=1}^{N} \rho_{k,n} f(A_{k,n}) \quad (2)\]

\[r_k^r = \min \left[ \sum_{n=1}^{N} \sum_{i=1}^{M} \rho_{k,n} f(C_{n,m}), \sum_{n=1}^{N} \sum_{i=1}^{M} q_{k,n,m} f(B_{k,n,m}) \right] \quad (3)\]

where

\[A_{k,n} = \frac{P_{BS} |H_{k,n}^0|^2}{N_0 + \sum_{r=1}^{M} q_{r,n} \beta_r P_{BS} |H_{k,n}^r|^2} \quad (4)\]

\[B_{k,n,m} = \frac{P_{BS} |H_{k,n,m}^0|^2}{N_0 + \sum_{r=1}^{M} \rho_{r,n} P_{BS} |H_{k,n,m}^r|^2} \quad (5)\]

\[C_{n,m} = \frac{P_{BS} |H_{n,m}^0|^2}{N_0} \quad (6)\]

\[|H_{k,n}^0|, |H_{k,n}^r|, |H_{k,n,m}^0|, |H_{k,n,m}^r| \] denote the channel gains of BS-MS link, BS-RS link and RS-MS link respectively. The \(N_0\) is the power of white Gaussian noises. The rate of the user \(k\) can be computed as

\[r_k = \alpha_k r_k^d + \beta_k r_k^r = \alpha_k \sum_{n=1}^{N} \rho_{k,n} f(A_{k,n}) + \beta_k \min \left[ \sum_{n=1}^{N} \sum_{i=1}^{M} \rho_{n,m} f(C_{n,m}), \sum_{n=1}^{N} \sum_{i=1}^{M} q_{k,n,m} f(B_{k,n,m}) \right] \quad (7)\]

A resource-allocation is considered as an optimal problem which achieves the maximum system throughput while meets the subscribers’ minimum rate requirement. Thus, the problem can be formulated as

\[\max \sum_{k=1}^{K} r_k \quad (8)\]

s.t. \(r_k = \alpha_k \sum_{n=1}^{N} \rho_{k,n} f(A_{k,n}) + \beta_k \min \left[ \sum_{n=1}^{N} \sum_{i=1}^{M} \rho_{n,m} f(C_{n,m}), \sum_{n=1}^{N} \sum_{i=1}^{M} q_{k,n,m} f(B_{k,n,m}) \right] \geq R; \quad \forall k \quad (9)\]

\[\sum_{k=1}^{K} \alpha_k = \sum_{k=1}^{K} \beta_k = 1; \quad \forall n \quad (10)\]

\[\sum_{n=1}^{N} q_{k,n,m} \leq 1; \quad \forall n \quad (11)\]

\[\alpha_k, \beta_k, \rho_{k,n}, q_{k,n,m} \in \{0,1\} \quad (12)\]

\[\alpha_k + \beta_k = 1; \quad \forall k \quad (13)\]

where constraint Eq. (9) ensures that each user must meet the minimum required rate \(R\). Constraint Eq. (10–13) guarantees that each subcarrier is occupied by only one transmitter-receiver pair in each hop, and BS and RS can share the subcarriers in the system. Constraint Eq. (13) ensures that the user \(k\) may choose direct transmission or relayed transmission.

Unfortunately, this resource-allocation problem is a combinatorial mixed integer programming problem, for which an exact solution usually involves an exhaustive search. Thus the problem is computationally extensive when the number of variables is large, that is N-P hard. Therefore, to simplify the problem, we proposed a suboptimal resource-allocation algorithm. We simplify the Eq. (7) and allocate the resource through two steps by utilizing AMC.

### 4 Suboptimal solution

As we know, in DF relay system, the rate of the relayed user is constrained by the lower one between the BS-RS link and the RS-MS link. And from the Lemma 1 in Ref. [5], we also know that the optimal solution to Eqs. (8)–(13) with continuous relaxation satisfies that the relayed user’s rate of the BS-RS link equates the rate of RS-MS link. In the suboptimal solution without continuous relaxation, the subcarrier allocation for second hop is related to the result of the subcarrier allocation for first hop. Besides, adaptive frequency reuse is adopted between the two hops in this system, i.e., the subcarriers used in RS-MS link reuse the subcarriers assigned to BS-RS or BS-MS link. Hence there are more available resources assigned to RS-MS link than the BS-RS link. However the suboptimal solution without continuous relaxation satisfies the relayed user’s rate of the RS-MS link is slightly greater than or equal to the rate of BS-RS link, i.e., the rate of the relayed user is mostly determined by the rate of the BS-RS link. The Eq. (7) can be simply written as

\[r_k = \alpha_k \sum_{n=1}^{N} \rho_{k,n} f(A_{k,n}) + \beta_k \sum_{n=1}^{N} \rho_{n,m} f(C_{n,m}) \quad (14)\]

From the Eq. (4), Eq. (5), and Eq. (14), it can be known that the system throughput is affected by the rate of the first hop and the interference to the first hop from the second hop. In an attempt to simplify the subcarrier allocation problem,
we consider the following three-step distributed resource allocation approach summarized as following steps:

1) The user is determined whether the transmission is through the direct link.

2) Subcarriers are assigned to the first hop through the optimal algorithm without considering interference from the second hop.

3) Subcarriers are assigned to the second hop with considering the minimum tolerable interference to the first hop.

By separately performing subcarrier allocation in each hop, this approach yields a suboptimal algorithm which is considerably simpler to implement than the integer programming problem. And the suboptimal algorithm will be presented in detail in following subsections.

4.1 Transmission mode selection

If the first hop link doesn’t be interfered, the SINR of the user transmitted directly can be changed as

\[ A'_{n} = \frac{P_{bs} |H|^{2}}{N_{0}} \]  

Without considering the multi-path fading, then \( A'_{n} = A'_{n} \), \( B'_{n} = B_{n} \), \( C'_{n} = C_{n} \) are assumed with the subcarrier assigned. Then the transmission model can be selected according to the metric from Ref. [9], which uses capacity of three wireless links in relay system (direct link / backhaul link / access link) to decide whether to transmit via RS or not. The bandwidth required for transmitting link / access link) to decide whether to transmit via RS or not.

4.2 Subcarrier allocation for the first hop

We suppose that the subcarrier doesn’t be assigned to the RS-MS link yet. Then the first hop doesn’t be interfered by the second hop. And the problem can be formed as

\[ \max \sum_{\rho \notin \Omega} r_k \]  

\[ \text{s.t.} \sum_{k=1}^{K} \rho_{k,n} = 1 \]  

\[ r_k \geq R; \quad \forall k \]  

\[ \sum_{k=1}^{K} \rho_{k,n} = 1; \quad \forall n \]  

\[ \rho_{k,n} \in \{0,1\} \]  

So the problem could be converted to assignment problem of the integer optimization. We can use Hungarian algorithm to solve this problem [10], which has a worst-case time complexity of \( O(N^3) \) for exhaustive search in theory. However the simulation time is actually much shorter in Ref. [11].

With the Hungarian algorithm, we obtain the assigned results of the first hop of each user. If both \( \beta_k = 1 \) and \( \rho_{k,n} = 1 \), it indicates that the subcarrier \( n \) is assigned to the BS-RS link. Then we can assign the subcarriers to the second hop link according to the set of \( \beta \) and \( \rho \).

4.3 Subcarrier allocation for the second hop

Let \( R_e \) denote the set of the users which select relayed transmission link, and \( R_d \) denote the set of the users which select direct transmission link; \( \forall \) denotes the set of the all subcarriers; \( A \) is the set of the subcarriers assigned to the BS-RS link; \( \Omega \) is the set of the subcarriers assigned to the BS-MS link; \( \Theta \) is the set of the subcarriers not to be assigned; \( M \) is the set of the relays. Because the relays are fixed, for ease of analysis, the throughput of the BS-RS link can be constant with different subcarrier. We assume \( \eta_{n} = f(C_{n}) \).

The detailed algorithm is proposed as Algorithm 1. In Line 7-12, firstly select the unassigned subcarriers and allocate resources to the second hop for user \( k \). Because of using the directional antenna in the relay for the BS-RS links, the RS-MS link doesn’t interfere with the BS-RS link using the same resource. If the unassigned subcarrier isn’t enough, subcarriers assigned to the BS-RS link are selected to be
reused in the second hop for user \( k \) (Line 13-22). As in AMC-based system, within a certain range of the SINR, the rates are the same. So the subcarriers with high SINR in the range can tolerate more interference. If the required subcarrier in second hop isn’t still enough, the RS-MS link can reuse the subcarriers which assigned to the BS-MS link without or with less effect using AMC (Line 23-33).

**Algorithm 1** Subcarrier allocation for the second hop

Input: \( K, M, N, \alpha_d, \beta_d, B_{k,n}, \rho_{k,s}, \eta_{k,n}, \Lambda_{k,s}, H_{k,n}^{\theta}, H_{k,n}^{\gamma}, P_s, N_0 \).

Output: \( q_{k,s,n} \).

Begin

\[
R_0 = \{ k \mid \beta_d = 1 \}; R_0 = \{ k \mid \alpha_d = 1 \}; T = \{ n \}; \Omega = \{ n \mid \rho_{k,s} \beta_d = 1, \forall k \}; A = \{ n \mid \rho_{k,s} \alpha_d = 1, \forall k \}; \Theta = T - \Omega - A; d = \text{card} (\Omega);
\]

// The number of elements in set \( \Omega \)

\[
\Omega' = (R_d) \ ;
\]

// Let the number in \( \Omega \) be in non-increasing order with SINR.

for \( i = 1: \text{card} (R_d) \)

\[
k = R_d(i); \quad \text{No'} = N, \rho_{k,s};
\]

// the number of the subcarrier in the first hop for user \( k \).

\[
\text{No}, f(\text{min } B_{k,n}) = \sum_{i=1}^{N} \rho_{k,s}, f(C_{k,n}) = \sum_{i=1}^{N} \rho_{k,s}, \eta_{k,n};
\]

// the number of the subcarrier in the second hop for user \( k \).

if \( \text{No} \leq \text{card} (\Theta) \)

for \( j=1: \text{x} \)

\[
n = \text{Bestsubcarrier} (\Theta); \quad q_{k,s,n} = 1; \quad \Theta = \Theta - \{n\}; \quad \text{x} = x+1;
\]

end

if \( \text{card } A \geq \text{No} - x \)

for \( j = 1: \text{No} - x \)

\[
n = \text{Bestsubcarrier} (A); \quad q_{k,s,n} = 1; \quad A = A - \{n\};
\]

end

\[
R_0 = R_0 - \{k\}; \quad d = d - \text{No'}; \quad \text{break};
\]

else

// Firstly assign the all rest subcarriers in \( \Theta \) to the user \( k \).

\[
x = 0;
\]

for \( j = 1: \text{card } \Theta \)

\[
n = \text{Bestsubcarrier} (\Theta); \quad q_{k,s,n} = 1; \quad \Theta = \Theta - \{n\}; \quad \text{x} = x+1;
\]

end

if \( \text{card } A \geq \text{No} - x \)

for \( j = 1: \text{No} - x \)

\[
n = \text{Bestsubcarrier} (A); \quad q_{k,s,n} = 1; \quad A = A - \{n\};
\]

end

\[
R_0 = R_0 - \{k\}; \quad d = d - \text{No'}; \quad \text{break};
\]

else

// Firstly assign the all rest subcarriers in \( A \) to the user \( k \).

for \( j = 1: \text{card } A \)

\[
n = \text{Bestsubcarrier } A; \quad q_{k,s,n} = 1; \quad A = A - \{n\};
\]

end

End

Once obtaining \( \alpha, \beta, \rho, q \), the system throughput can be compute as

\[
C = \sum_{k=1}^{K} \alpha_k \sum_{n=1}^{N} \rho_{k,s}, f(A_{k,n}) + \beta_k \sum_{n=1}^{N} \rho_{k,s}, f(C_{k,n})
\]

Therefore, the time complexity of suboptimal algorithm is \( O(N^3 + KN) \) in the worst case theoretically.

**5 Simulation**

This section compares the performance of adaptive reuse scheme in full-duplex relay with the orthogonal scheme. A relay enhanced OFDMA single cellular is assumed. The BS is located in the center of each cell, and six fixed RSs are placed on the lines connecting BS and six cell vertices. Each RS is 2/3 radius away from the BS so as to achieve the optimal system performance. We also assume that all MSs remain stationary and the channel condition doesn’t change. The simulation parameters are listed in Table 2, which refer mainly to Ref. [12]. In order to avoid only simulating a single cell while to simulate a real cellular scenario we add the inter-cell interference and assume it is constant, and make the user in cell edge only choose the lowest modulation and coding scheme.

**Table 2** Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site-to-site distance/km</td>
<td>1.5</td>
</tr>
<tr>
<td>Carrier frequency/GHz</td>
<td>2.5</td>
</tr>
<tr>
<td>System bandwidth/MHz</td>
<td>2</td>
</tr>
<tr>
<td>Lognormal shadowing/dB</td>
<td>8</td>
</tr>
<tr>
<td>Number of points in full FFT</td>
<td>1024</td>
</tr>
<tr>
<td># of used subcarriers</td>
<td>128</td>
</tr>
<tr>
<td># of the multipath</td>
<td>3</td>
</tr>
<tr>
<td>BS-MS and RS-MS path loss</td>
<td>Baseline test scenario</td>
</tr>
<tr>
<td>BS-RS path loss</td>
<td>802.16j EVM Type D</td>
</tr>
<tr>
<td>BS and RS Tx power/ dB</td>
<td>46/38</td>
</tr>
<tr>
<td>Thermal noise density (dBm Hz^-1)</td>
<td>-174</td>
</tr>
</tbody>
</table>

Fig. 2 shows the result for the adaptive reuse resource allocation scheme with two antennas, the adaptive reuse
resource allocation scheme with single antenna, and the orthogonal resource allocation scheme with single antenna. With the single antenna model, the BS-RS link and the RS-MS link use the same subcarriers but in different phases, i.e. the relays operate in the half-duplex. Hence the orthogonal resource allocation scheme with single antenna as the subcarriers allocation scheme in Ref. [5], and the adaptive reuse resource allocation scheme with single antenna, using the reuse scheme, proposed in this paper, are under the half-duplex model relay. The minimum required rate $R$ of each user is 70 kbit/s. From the figures we can see that with the number of the users $K$, the adaptive reuse resource allocation scheme with single antenna can improve 10.3% system throughput compared to the orthogonal one, and the adaptive reuse resource allocation scheme with two antennas can improve 12.44% the system throughput compared to the adaptive reuse resource allocation scheme with single antenna, i.e. the increment in system throughput is caused by the two-antenna model. Since there are an omni-directional antenna for the RS-MS links and a directional antenna for the BS-RS link in the two-antenna model RS, the RSs receive the signals directionally and transmit omni-directionally in downlink. This two-antenna model can make the RS operate in full duplex model, while the single-antenna can’t. And the RS receives the signals directionally; the BS-RS link can’t be interfered by RS-MS link in full duplex model. It can obtain spatial diversity, thereby the BS-RS and RS-MS can reuse frequency at the same time to obtain more frequency resources. Mentioned above are the reasons why the adaptive reuse resource allocation scheme with two antennas has higher system throughput compared to the adaptive reuse resource allocation scheme with single antenna. However it is worth to mention that the blue line increases firstly and then decreases to the same as the other lines. The reason is shown in Fig. 3. As the number of users increases, the number of the direct transmission users increases. These users have better path gain than relayed transmission ones. Using Hungarian algorithm, it assigns more subcarriers to direct users, and less to relayed users. Then the relayed users affect the system throughput less by the adaptive reuse resource allocation scheme with two antennas. If the number of users increases large enough, the subcarriers are all assigned to the direct transmission user, the three line will coincide in Fig. 2. The Fig. 4 is the result of the throughput for the adaptive reuse resource allocation scheme using two antennas under the situation in which both $K$ and $R$ increase. It can be shown that both $K$ and $R$ can impact on the system throughput, yet $K$ affect greater.

6 Conclusions

In this paper, we present an AMC-based dynamic resource allocation scheme in adaptive frequency reused OFDMA-relay networks by using the DF relay with two independent antennas. With the spatial multiplexing, the resource in BS-RS link can be reused by RS-MS link well. Then with the help of AMC, BS and RS can reuse the same subcarriers. The results show that our proposed suboptimal algorithm can solve the N-P hard optimal algorithm and improve the system throughput compared with other schemes.

To p. 71
adjutable parameters. The proposed algorithm can improve the performance of the traditional distributed algorithm in both spectral efficiency and normalized frequency efficiency. In addition, due to the proposed scheme is implemented in distributed manner, it is easy to combine with fairness criterions.

Acknowledgements

This work was supported by the Sino-Swedish IMT-Advanced Cooperation Project (2008DFA11780), the Canada-China Scientific and Technological Cooperation (2010DFA11320), the National Natural Science Foundation of China (60802033, 60873190), the Hi-Tech Research and Development Program of China (2008AA01Z211), the Fundamental Research Funds for the Central Universities (2009RC0308).

References

12. Salo J, Del Galdo G, Salmi J, et al. MATLAB implementation of the 3GPP spatial channel model. 3GPP. TR 25.996, 2005

(Edited: WANG Xu-ying)