Research on Critical Technologies for Synergistic Relay Link Layer in Wireless Communications

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Abstract

This paper studies the wireless resource management and scheduling of synergistic relay system link layer. In order to optimize power of collaborative communications relay node and make other wireless resources allocation rational, this paper use a single cell relay system as a model to study efficient optimal allocation and cooperation strategies of resource in relay system. First, this paper proposes a power allocation algorithm that is based on convex optimization theory, and the maximize system capacity of it is the objective function, this algorithm utilizes ellipsoid algorithm to solve this optimization problem, this method greatly improves the selection of step length of the sub-gradient and convergence stability. Second, combine the user access fairness factors and introduce improved analytic hierarchy process to OFDMA resource scheduling, propose a joint optimization objective function of system subcarrier allocation, power distribution, transmission mode selection and relay selection. Obtain every relay node fairness weight of the system by the analytic hierarchy process, schedule priority of a user according to the system fairness weighting coefficient values. This method makes the system fair access and spectrum utilization efficiency to do an effective compromise.

Keywords: Wireless Communication; Relay System; Link Layer; Radio Resource Management

1 Introduction

Collaborative communication introduces spatial diversity by users sharing the antenna and it becomes effective against multipath fading of wireless channel, so it has become a hot research field of wireless communications in recent years. How to allocate and manage relay node is a key technology in cooperative communications. Collaborative communication system based on the relay node is more complex than the traditional direct communication, because the introduction of the relay will be consuming more bandwidth, time slot, or power, and other system resources. In order to improve the efficiency of power distribution, minimize interference between users, manage and allocate the source node and the relay node transmit power effectively. Although De

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Morales [1, 5] study some node power distribution of relay system, but on one hand, the degree of complexity of the algorithm is too high to be suitable for general engineering applications, on the other hand it does not take full advantage of the space resources to make optimal allocation of resources [4, 7, 8].

This section examines the power allocation problem of the relay system, utilizes ellipsoid method to solve the optimization problem. This method greatly improves the selection of step length of the sub-gradient and convergence stability. At the same time it maintains the overall system performance, and reduces power consumption.

2 The Relay System Model

As Fig. 1 show, a source node $S$ transmits a signal to a destination node $D$, there are $K$ relay nodes $R = \{1, 2, \ldots, K\}$ in the transmission process. First, the source node broadcasts the transmitted signal, the relay monitors; then selected the optimal relay from all relays; here assumed that each of the sub-carrier transmission only uses a relay, and the relay utilizes the same subcarrier as the transmission node to forwarded; the channel is the Rayleigh Channel model, and each of transmission is mutually independent. The mode of relay is decoding forwarding. Relay nodes receive the full channel state information.

Fig. 1: The model of collaboration communication system

The channel impulse response coefficients of the source node to the destination node, the source node to the number $i$ relay node and the number $i$ relay node to the destination node are $h_{sd}, h_{sr_i}, h_{rd_i}$, and they are mutually independent random variables; at the same time, they are White Gaussian noise which the respective corresponding channel capacity are $l_{sd}, l_{sr_i}, l_{rd_i}$; the mean of channel noise is 0, variance additive is $N_0$. Assuming that the total power of one transmission is limited. $p_s$ and $p_{r_i}$ are respectively the transmit power of the source node and the $i$ relay node, $\gamma_{sd} = p_s h_{sd}^2 / l_{sd} N_0$ is received signal-to-noise ratio of the destination node to the source node; $\gamma_{sr_i} = p_s h_{sr_i}^2 / l_{sr_i} N_0$ is received signal-to-noise ratio of relay node $i$ to source node; $\gamma_{rd_i} = p_{r_i} h_{rd_i}^2 / l_{rd_i} N_0$ is received signal-to-noise ratio of destination node to relay node $i$. Wherein the capacity of the channel $l_{sd}, l_{sr_i}, l_{rd_i}$ are respectively proportional to the square of the channel coefficient $h_{sd}, h_{sr_i}, h_{rd_i}$ (Shannon formula), thus $\gamma_{sd}, \gamma_{sr_i}, \gamma_{rd_i}$ can be expressed as the channel signal-to-noise ratio in the above form to multiple a coefficient. On the basis of a given number of the relay node, the target of the power distribution is a reasonable allocation of transmission power between a source node and a plurality of relay nodes, to maximize the channel capacity.
The optimization problem can be described as follows [2, 3]:

\[
\begin{align*}
\text{Max} & \quad \ln [p_s h^2_{sd}/l_{sd}N_0 + \sum_{i=1}^{K} p_r h^2_{r,d}/l_{r,d}N_0] \\
\text{s.t.} & \quad p_s + ^T p_r \leq P, p_s \geq 0, p_r \geq 0
\end{align*}
\]

(1)

This formula does not contain +1 compared with Shannon formula, this is because when calculate the maximum of the optimization problem, mathematically, remove +1 does not affect the incremental and regressive of the formula, in order to make it easy to calculate, remove +1 items. 

\(P\) is the total transmit power constraint of the source node and the relay node, here assumes that the power satisfies the normalized constraint condition, and that is \(P = 1\).

Solutions A and B of this model are transmission power value of the source node and the relay node that make the article link channel capacity to maximize. \(r_i\) is the optimal relay node among all the selected.

3 Power Allocation Algorithm Based on Convex Optimization in Relay System

Formula (1) is a typical convex optimization problem (the proof see Appendix 5), here we can use Karsh-Kuhn-Tucker (KKT) optimization method to calculate, corresponding Lagrange The equation of formula (2) is:

\[
L(p_s, p_r, \lambda, \mu, \eta) = \ln [p_s h^2_{sd}/l_{sd}N_0 + \sum_{i=1}^{K} p_r h^2_{r,d}/l_{r,d}N_0] - \lambda(p_s + ^T p_r - P) + \mu p_s + \eta p_r
\]

(2)

\(\lambda = (\lambda_s, \lambda_1, \cdots, \lambda_k)^T\) in formula (3) is \(k + 1\) dimensional dual vector. Corresponding dual function can be written as:

\[
G(\lambda) = \max_{p_s, p_r} \left\{ L(p_s, p_r, \lambda) \right\} \quad \text{s.t.} \quad p_s + ^T p_r \leq P, p_s \geq 0, p_r \geq 0
\]

(3)

\(\mu, \eta\) are minter and can be negligible. Constraints \(s.t.\) have zero duality gaps, so we can calculate through dual optimization, that is:

\[
P1 : \min G(\lambda) \quad \text{s.t.} \quad \lambda_j \geq 0, \quad j = s, 1, 2, \cdots, K
\]

(4)

The ellipse algorithm can be used to solve problem, see \(\lambda\) as the center, ellipsoid shape defined by a semi-positive definite matrix can be expressed as:

\[
E(S, \lambda) \approx \{x | (x - \lambda)^T S^{-1} (x - \lambda) \leq 1\}
\]

(5)

Let \(\lambda_i, S_i\) and \(g_i\) denote Part \(i\) the iterations center of the ellipse, the shape matrix \(G(\lambda)\) is the gradient in the center of the ellipse, remove half of the ellipsoid based on \(g_i\) when iterating, and this will generate the minimum ellipsoid ball that contains the other half ellipsoid for the next iteration.

Algorithm 1
1) Give an initial ellipsoid $E(S_0, \lambda_0) \subseteq R^{K+1}$ that contains the optimal dual vector $\lambda^*$, and let $i = 0$;

2) Solve the dual function (3), and that can get the optimal resource allocation $p_{r_i}$ and $p_s$ whose dual vector is the center of the ellipsoid $\lambda_i$;

3) Calculate dual function $g_i$ in sub-gradient $\lambda_i$;

4) Update ellipsoid, and let $i = i + 1$.

\[ g_i = g_i / \sqrt{g_i^T S_i g_i} \]  \hspace{1cm} (6)

\[ \lambda_{i+1} = [\lambda_i - S_i g_i / (K + 2)]^+ \]  \hspace{1cm} (7)

\[ S_{i+1} = \frac{(K + 1)^2[S_i - 2S_i g_i g_i^T S_i / (K + 2)]}{[(k + 1)^2 - 1]} \]  \hspace{1cm} (8)

$(x)^+$ in formula represents each element of the vector $x$ are satisfied that $x_j = \max(x, 0)(j = 1, 2, \cdots, K + 1)$;

5) Iterative steps 2–4 until the algorithm converges.

Use the method above to calculate the formula (3). We use decoding forwarding to forward, solution method is as follows:

Lagrange equation can be obtained by the formula (2), analyzing the condition KKT, we can assume that $p_s$ is known and do the partial derivative of $p_{r_i}$, let $\partial L / p_{r_i} = 0$, we can obtain that:

\[ \partial L / p_{r_i} = \gamma_{r,j} d / (\gamma_{sd} + \sum_{i=1}^{K} \gamma_{r,j} d) - \lambda + \eta_i = 0 \]  \hspace{1cm} (9)

\[ \eta_i p_{r_i} = 0, p_{r_i} \geq 0, i = 1, 2, \cdots, N \]  \hspace{1cm} (10)

Formula below can be obtained from the above two equations:

\[ p_{r_i} = \{(\gamma_{sd} / p_s) - \gamma_{sd} - \sum_{j \neq i} \gamma_{r,j} d \gamma_{r,j} d, 0\}^+ \]  \hspace{1cm} (11)

In the formula, \{(x, 0)^+ = \max\{x, 0\}. Do the partial derivative of $p_s$ under the condition that $p_{r_i}$ is known. And let $\partial L / p_s = 0$, the transmit power of the source node is:

\[ p_s = \{(\gamma_{sd} / p_s) - \gamma_{sd} - \sum_{j \neq i} \gamma_{r,j} d \gamma_{r,j} d, 0\}^+ \]  \hspace{1cm} (12)

Sub algorithms 1

1) Cellular $p_{r_i}$ and $p_s$ according to the formula (11) and (12).

2) Let $p_s = p_s^{max}$, calculate $p_{r_i}$ from the formula (11), if $p_{r_i} \leq p_{r}^{max}$, calculate the objective function value of $L(p_s, p_{r_i}, \lambda)$; otherwise set it to 0;

3) Let $p_{r_i} = p_{r}^{max}$, calculate $p_s$ from the formula (12), if $p_{r_i} \leq p_{r}^{max}$, calculate the objective function value of $L(p_s, p_{r_i}, \lambda)$; otherwise set it to 0;

4) Compare the objective function value of $L(p_s, p_{r_i}, \lambda)$ in steps 2 and 3, if the larger of the values is greater than 0, the solution of objective function is the corresponding value of the power, otherwise, let $p_{r_i} = p_s = 0$. 


In the formula $p_{s}^{\max}$, $p_{r}^{\max}$ are respectively the maximum power value of the default source node and the relay node. According to algorithm 1, we can use the iterative optimization method to get the specific values of $p_{r}$ and $p_{s}$. Then substitute into the second step of the algorithm 1, use the ellipsoid method to complete the dual optimization problems $P1$. After the algorithm 1 converges, according to obtained optimal dual vector, $P1$ can be quickly obtained, thereby complete the allocation of resources of the system power.

4 Results and Analysis

Simulation scenarios: we assume that source node is at (0, 0), the destination node is located at (10, 0), relay nodes are located within a region of the central area (5, 0), use Monte Carlo (Monte Carlo) simulation method, relay system based on OFDM, can quickly regenerate a relay node every time. Fading factor of the line-of-sight transmission between the base station BS relay station $RS$ is 2.35, The relay station $RS$ and the mobile station $MS$, the base station $BS$ and the mobile station $MS$ use the non-line-of-sight transmission, and their fading factors both are 3.75. Radio channel is frequency-selective channel, and use 6-path Rayleigh flat fading channel model. The simulation parameters shown in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell radius/m</td>
<td>600</td>
</tr>
<tr>
<td>Center frequency/GHz</td>
<td>2</td>
</tr>
<tr>
<td>System bandwidth/MHz</td>
<td>1</td>
</tr>
<tr>
<td>Sub-carriers</td>
<td>128</td>
</tr>
<tr>
<td>The maximum power of the base station/dBm</td>
<td>46</td>
</tr>
<tr>
<td>Maximum power of relay station/dBm</td>
<td>38</td>
</tr>
<tr>
<td>Noise power spectral density/(dBm · Hz-1)</td>
<td>-174</td>
</tr>
<tr>
<td>Bit Error Rate BER (3.1.3.1 Section)</td>
<td>10-4</td>
</tr>
<tr>
<td>The lowest rate of the user/(kbps)</td>
<td>50</td>
</tr>
</tbody>
</table>

In the text of this section simulation the optimal ellipsoid is based on power allocation algorithm, the weighting factor and the user data rate is the system optimization objectives in the simulation, do the optimal resource management discussion and simulation for relay OFDM system. At the same time as a comparison, we compared several similar relay system power allocation algorithm, it contains no relay OFDM system of direct communication link, the average power allocation algorithm, suboptimal power allocation algorithm and so on.

4.1 Performance analysis of optimal power allocation

Set parameters in accordance with the above-described simulation environment, In addition, equip each relay node with an antenna, the cyclic prefix length of the channel signal is 1/4 length of OFDM signal. The procedure makes a simple least mean square (LMS, Least Mean Square) channel estimation, modulation schemes is QPSK, the maximum delay of the channel length is seven symbols, the signal-to-noise ratio of the channel changes from -10dB to 15dB, simulation conditions is that the system is in perfect synchronization. Do simulation measurement of power value on the nodes with the change of the signal-to-noise ratio, compare the power situation under
the optimal allocation and average distribution situation mentioned in this section, as shown in Fig. 2. At the same time, we also carried out a simulation for the spectral efficiency of the two algorithms, and compare the utilization of the spectrum resources when the two algorithms are in different signal-to-noise ratio, to a certain extent, this reflects the efficiency and capacity of the system utilization, the results shown in Fig. 3.

Fig. 2: Comparison of power distribution

In addition, we simulated the utilization of the spectrum efficiency in the relay system, the situation is shown in Fig. 3. With the improvement of the signal-to-noise ratio, the optimal
power allocation algorithm that targets at maximize system capacity is almost the same as average power allocation algorithm in spectral efficiency, as Fig. 3 shows, the optimal power allocation algorithm is slightly better than the average power distribution, this is due to the channel model of the two power allocation strategies are consistent with each other, and system parameters are set essentially the same, it is estimated that the channel spectrum function is consistent with each other too, so both spectrum efficiency (data rate) is basically the same. As the signal-to-noise ratio continues to upgrade, and ultimately both the spectrum utilization ratio is the same. This result can provide experimental reference data for subsequent nodes power distribution simulation experiment.

Fig. 4 shows the relationships between the system capacity in increments and the relay number, as system capacity incremental the improves, the number of the available relay nodes decreases, the capacity of the system slowly becomes saturated, but at the same time because of the decrease of the relay, it can bring the reduction of computing complexity; conversely, if further increase the number of available relay nodes, then the increase of the system capacity will bring the improvement of the computational complexity degree. As Fig. 4 show, take the compromise relationship between the system performance and implementation complexity into consideration, the optimum channel capacity gain threshold should be at about 10%.

Next, do simulation for the error performance of the system. We compare the error performance of three methods in this simulation: direct communication link (without repeaters) system cell model, the average power allocation algorithm cell model, as well as the relationship of the bit error rate and signal-to-noise ratio of the optimal power allocation algorithm in this section. Each node is equipped with an antenna in this model, and we select QPSK to be modulation scheme, and set the sample rate of the channel to be 10K bits/s, and still keep the number of the relay nodes at 4, the settings of the other model parameters are the same as the parameters in the previous one. In the simulation that based on bit error rate, this section simulate the impact of the system error performance from the power allocation algorithm under the conditions of different signal-to-noise ratio, simulation results are as follows:

Fig. 5 shows how the error rate changes with the bit signal-to-noise ratio in different options. The error rate of the conventional cell approximates a straight line with the enhancement of the signal-to-noise ratio, this is due to the linear relationship of its error performance and signal to noise ratio, the simulation meet theoretical derivation. As it can be seen from the comparison of the average power allocation algorithm and optimal power allocation algorithm, when the level of the bit error rate is 10-3, the use of optimal power allocation algorithm improves the optimization of the channel matrix about a gain of 4dB (average), optimal power allocation algorithm and
average power allocation algorithm have almost the same impact on error performance of the system, optimal power allocation algorithm and suboptimal power allocation algorithm have almost the same error performance, there are no longer sub-optimal algorithm simulation in this section. It also can be seen from the figure that, in the the low signal-to-noise ratio and a high signal-to-noise ratio condition, power allocation algorithm has almost the same impact on error performance, this is because the data rate of the system has been set, the optimization goal \( L(p_s, p_r, \lambda, \mu, \eta) \) only do the optimization deformed for power distribution of the system and the capacity, it has substantially no effect on the level of system error, and therefore it also will not affect the error of the system encoder.

5  Conclusions

In this section we study in collaborative communication to select the optimal relay nodes and problems of optimal power allocation between the source node and the relay node. Use the channel capacity formula, combine the power restrictions, use theory of knowledge related to convex optimization to achieve equitable distribution of resources, make full use of the cooperative diversity capacity of relay node, and improve system capacity. As a follow-up study, we can consider to further reduce the complexity of the algorithm, and reduce the proportional square relationship of the number of trunks to a linear relationship; on the other hand, this article uses the system resources that the base station centralized schedules power, so we may consider the idea of distributed computing, disperse resource scheduling calculations to the base station and relay and collaboration to make them collaborated in order to reduce the load of the base station and system feedback overhead.

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