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OPTIMAL POWER ALLOCATION SCHEMS FOR DECODE-AND-FORWARD MIMO-OFDM RELAY SYSTEM

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ABSTRACT

Cooperative relaying strategies have become a major topic in the wireless research community and that decode-and-forward relay technology can suppress noises effectively. In order to achieve the maximum capacity of the system, the optimal allocation algorithm is proposed under the assumption that all nodes know accurate channel instantaneous state information (CSI). Because it is hard to obtain a general solution expression during deducing, we provide an iterative power allocation algorithm with a simpler structure. Numerical results show that adopting the proposed power allocation algorithm, the capacity of MIMO relay channel with DF relay scheme can improve 1.4 bps/Hz. Through analysis, a proper iterative precision value can be found to keep the good balance between system capacity and complexity. To further improve the system capacity, we use the subcarrier pairing strategy before power allocation.

KEYWORDS: DF relay; power allocation; MIMO; OFDM

I. INTRODUCTION

One of the challenges for future wireless communication systems is to provide high data rate wireless access at high quality of service. Novel technologies that could radically increase spectral efficiency and improve link reliability are therefore needed to meet the requirements mentioned above. Cooperative relay, known as a powerful method to combat fading and increase robustness for wireless communication, is being considered [1-2]. In a relay channel, the source sends information to the relays. The relays amplify (AF) or detect (DF) the received signals and then forward them to the destination[3-5]. In this paper, the focus lies on DF, which has an advantage that the transmission can be optimized for both links [6-7], and will not amplify the noise included in the received signal.

From the perspective of information theory [8-9], channel capacity depends on the SNR of the received signal. So, how to allocate the limited power among nodes to achieve the maximum channel capacity or SNR at the receiver is an important issue. In [10], the authors determine power allocations for multiple orthogonal AF relays which maximize the average SNR at the receive node using the maximal-ratio combining technique. [11] just proposed the optimal power allocation scheme of AF relay nodes (transmit node) when the transmit node (AF relay node) power is fixed. In [12]-[13], optimal power allocations between single antenna transmit node and relay node are discussed for the case of a joint transmit power constraint.

In this paper, we aim to design efficient algorithm for allocating power resources in DF MIMO-OFDM relay system. We first formulate the problem on optimal power allocation for the system. Then an iterative power allocation algorithm with a simpler structure is proposed to achieve a near-optimal solution.

The rest of the paper is organized as follows. In section II, the system model for the 2-hop DF MIMO-OFDM relay channel is described in detail, and the terms used in this paper are defined. The PA scheme based on the channel capacity is analyzed in section III. Section IV compares the capacity of the proposed scheme with those of several other schemes. Conclusions are made in the last section.

II. SYSTEM MODEL

A DF MIMO-OFDM relay system is illustrated in Fig.1. The relay node(RN) attempts to detect the transmit node's(TX) bits and then retransmits the detected bits. The node operates in the time-division half-duplex mode: the TX transmits the symbol to RN at the first timeslot, and the RN relays the received signal to the receive node (RX) at the second timeslot. Assume the receive node isn't in the communication range of the transmit node. The receive node is not able to receive the signal from the transmit node directly.

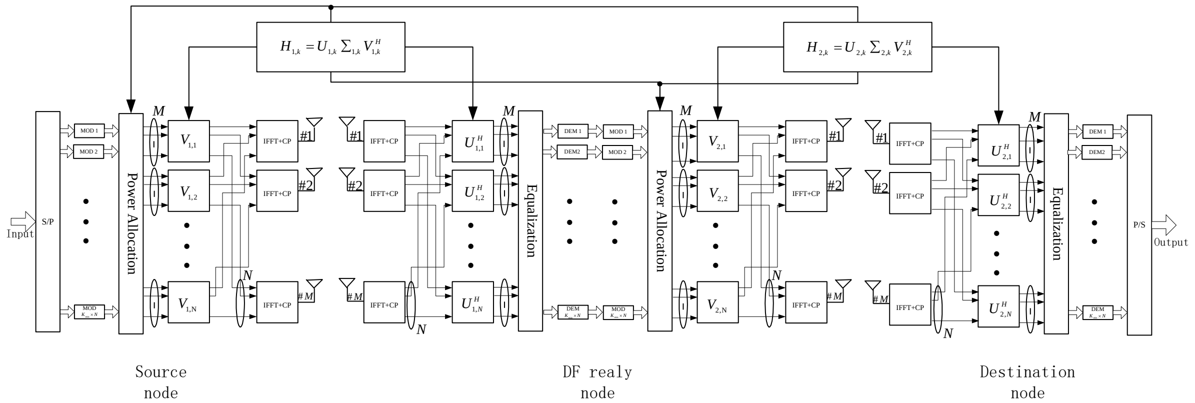

Fig.1. Structure of decode-and-forward MIMO-OFDM relay system

The number of antennas equipped in the TX, RN and RX is equal to M. The frequency band is divided into N sub-channels. A data stream is fed into the Serial/Parallel block, which in turn segments the data stream into $M \times N$ parallel streams. Then, the adaptive power loading is implemented after the modulator bank. We assume that all nodes have known the channel state of both two hops. OFDM is used with a cyclic prefix, so ISI can be neglected and a frequency-selective channel is divided into N frequency-flat sub-channels. The channel matrix from TX to RN and from RN to RX within the kth OFDM subcarrier is denoted by $H_{1,k}$ and $H_{2,k}$ respectively. Assume all channel matrices have full rank. The singular value decomposition of the channel matrices is given by Equation (1) [14].

$$\begin{aligned} \boldsymbol{H}_{1,k} &= \boldsymbol{U}_{1,k}\Sigma_{1,k}\boldsymbol{V}_{1,k}^H \\ \boldsymbol{H}_{2,k} &= \boldsymbol{U}_{2,k}\Sigma_{2,k}\boldsymbol{V}_{2,k}^H \end{aligned} \quad (1)$$

Where $(\bullet)^H$ $(.)^H$ represents hermitian transposition; $U_{1,k}$ and $V_{1,k}$ are $M \times M$ dimensional unitary matrix ($U_{i,k}^H U_{i,k} = I, V_{i,k}^H V_{i,k} = I, i = 1,2., \boldsymbol{V}_{i,k}^H V_{i,k} = \boldsymbol{I}$, I is unit matrix); $\Sigma_{1,k}$ is $M \times M$ dimensional diagonal matrix, $\lambda_{i,k,j}(j = 1,2,..M)$ is the diagonal element of $\Sigma_{1,k}$. Therefore, each sub-carrier on the MIMO channel is transformed into M sub-channels and there are a total of $M \times N$ sub-channels in system.

Under the assumption that the RN knows the perfect CSI of all channels, TX adjusts the power of various sub-channel signals in accordance with power allocation algorithm firstly in the first slot. Then signals are transmitted after multiplied by $V_{1,k}$; The received signals are multiplied by $U_{1,k}^H$ and then are decode-forwarded after multiplied by $V_{2,k}$ in the second slot. RX restores the signals which are multiplied by $U_{2,k}^H$before. According to previous analysis, First-hop transmission and second-hop transmission of DF MIMO-OFDM relay system can be described as Equation (2) and Equation (3) respectively

$$R_k = U_{1,k}^H H_{1,k}\sqrt{P_{1,k}\frac{G_{1,t}G_{1,r}h_{1,t}^2h_{1,r}^2}{d_1^\alpha}}V_{1,k}S_k + U_{1,k}^H N_{1,k} = \sqrt{P_{1,k}\frac{G_{1,t}G_{1,r}h_{1,t}^2h_{1,r}^2}{d_1^\alpha}}\Sigma_{1,k}S_k + \tilde{N}_{1,k} \quad (2)$$

$$D_k = U_{2,k}^H H_{2,k}\sqrt{P_{2,k}\frac{G_{2,t}G_{2,r}h_{2,t}^2h_{2,r}^2}{d_2^\alpha}}V_{2,k}\tilde{R}_k + U_{2,k}^H N_{2,k} = \sqrt{P_{2,k}\frac{G_{2,t}G_{2,r}h_{2,t}^2h_{2,r}^2}{d_2^\alpha}}\Sigma_{2,k}S_k + \tilde{N}_{2,k} \quad (3)$$

Where $S_k$is the transmitted signal vector with the covariance matrix $E\{S_k S_k^H\} = I\tilde{R}_k$is the result of decoding in relay node $(\tilde{R}_k = S_k)$, $\boldsymbol{P}_{i,k} = diag[p_{i,k,1}, p_{i,k,2}, ..., p_{i,k,M}]$ $P_{i,k} = diag[P_{i,k,1}, P_{i,k,2}, ... P_{i,k,M}]$ indicates transmit power of sub-channels. $\tilde{N}_{i,k}$denotes the $U_{i,k}^H N_{i,k}$ and $E\{\tilde{N}_{i,k}\tilde{N}_{i,k}^H\} = N_i I.G_{i,t}$ and $G_{i,r}$are transmitted and received antenna gain of the ith hop. $h_{i,t}$and $h_{i,r}$are antenna transmitted and received height, respectively. $d_1$and $d_2$denote the distance of the first hop from TX to RN and second hop from RN to RX respectively. Assume that all path loss exponents are the same and equal to α, which usually takes a value from 2.5 to 6 depending on the terrain and foliage [14].

III. OPTIMAL POWER ALLOCATION SCHEME

The capacity of the first hop and the second hop with the power allocation can be expressed as Equation (4) and Equation (5).

$$C_1 = \sum_{k=1}^{N} W\log_2 \det(I + \frac{P_{1,k}G_{1,t}G_{1,r}h_{1,t}^2 h_{1,r}^2 \Sigma_{1,k}^2}{N_1 W d_1^{\alpha}}) = W\sum_{k=1}^{N}\sum_{j=1}^{M}\log_2(1 + \frac{P_{1,k}G_{1,t}G_{1,r}h_{1,t}^2 h_{1,r}^2 \lambda_{1,k,j}^2}{N_1 W d_1^{\alpha}}) \quad (4)$$

$$C_2 = \sum_{k=1}^{N} W\log_2 \det(I + \frac{P_{2,k}G_{2,t}G_{2,r}h_{2,t}^2 h_{2,r}^2 \Sigma_{2,k}^2}{N_2 W d_2^{\alpha}}) = W\sum_{k=1}^{N}\sum_{j=1}^{M}\log_2(1 + \frac{P_{2,k}G_{2,t}G_{2,r}h_{2,t}^2 h_{2,r}^2 \lambda_{2,k,j}^2}{N_2 W d_2^{\alpha}}) \quad (5)$$

Where W is sub-carrier bandwidth. Making use of the max-flow min-cut theory [11], the upper bound of the channel capacity can be given as Equation (6)

$$C_{upper} = \min\{C_1, C_2\} = W\sum_{k=1}^{N}\sum_{j=1}^{M}\min\begin{pmatrix}\log_2\left(1 + \frac{p_{1,k,j}G_{1,t}G_{1,r}h_{1,t}^2 h_{1,r}^2 \lambda_{1,k,j}^2}{N_1 W d_1^{\alpha}}\right)\\ \log_2\left(1 + \frac{p_{2,k,j}G_{2,t}G_{2,r}h_{2,t}^2 h_{2,r}^2 \lambda_{2,k,j}^2}{N_2 W d_2^{\alpha}}\right)\end{pmatrix} \quad (6)$$

Optimal power allocation problem of DF MIMO-OFDM relay system can be described as Equation (7)

$$C = \max\sum_{k=1}^{N}\sum_{j=1}^{M}\min\{C_{i,k,j}, C_{2,k,j}\} \quad (7)$$

Where P_{total} is the total power which is fixed. According to Equation (7), the maximum capacity of DF MIMO-OFDM relay system can be achieved by optimizing parameter $P_{i,k,j}$ under a certain constraint.

According [12], we can know that the maximum of C is achieved when $C_{1,k,j} = C_{2,k,j}$, and then the optimization problem can be transformed into Equation (8)

$$C = \max\sum_{k=1}^{N}\sum_{j=1}^{M} C_{1,k,j} \quad \begin{aligned} & C = \max\sum_{k=1}^{N}\sum_{j=1}^{M} C_{1,k,j} \\ & s.t. \sum_{i=1}^{2}\sum_{k=1}^{N}\sum_{j=1}^{M} p_{i,k,j} = P_{total} \\ & C_{1,k,j} = C_{2,k,j} \end{aligned} \quad (8)$$

It is hard to provide closed-form representation for the solution and the directly optimizing algorithm involves too complicated structure. So we provide an iterative power allocation algorithm with a simpler structure to implement the optimal power allocation.

Detailed realization of the algorithm is described in Fig.2. Firstly, all the variables are initialized.

From the process above, it can be seen that θ decides the number of repeat, and the smallerθ tends to be, the larger capacity can be got. In next section, the idea will be confirmed.

To further improve the system capacity, we use the subcarrier pairing strategy before the power allocation. Without proving optimality here, we state that the optimal assignment strategy pairs the TX-RN subcarrier having the kth largest SNR with the RN-RX subcarrier having the kth largest SNR for all k=1,…N. This pairing strategy maximizes both sum of SNRs and sum capacity over all subcarriers.

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Step 1 : *Initializaion*

$$p_{1,k,j} = p_{2,k,j} = P/(2NM) \quad \forall k \in N \, and \, j \in M$$

$$\Delta p = P/(4NM)$$

Step 2 : *Calculate* $C_{1,k,j}$ *and* $C_{2,k,j}$

$$c_{1,k,j} = \log_2(1 + \frac{p_{1,k,j} G_{1,t} G_{1,r} h_{1,t}^2 h_{1,r}^2 \lambda_{1,k,j}^2}{N_1 W d_1^{\alpha}})$$

$$c_{2,k,j} = \log_2(1 + \frac{p_{2,k,j} G_{2,t} G_{2,r} h_{2,t}^2 h_{2,r}^2 \lambda_{2,k,j}^2}{N_2 W d_2^{\alpha}})$$

Step 3 : *iterative*

While $|C_{1,j,k} - C_{2,j,k}| > \theta$

if $C_{1,j,k} > C_{2,j,k}$

$$p_{1,k,j} = p_{1,k,j} - \Delta p$$

$$p_{2,k,j} = p_{2,k,j} + \Delta p$$

else

$$p_{1,k,j} = p_{1,k,j} + \Delta p$$

$$p_{2,k,j} = p_{2,k,j} - \Delta p$$

end if

$$\Delta p = \Delta p / 2$$

Step 4 : *Repeat Step* 2 *and Step* 3

Fig.2.iterative power allocation algorithm

IV. NUMERICAL RESULTS

In this section, simulations are performed to evaluate the performance of the algorithms described in section III. Three solutions are introduced for comparison: 1.iterative power allocation without subcarriers pairing (NSP-PPA); 2. iterative power allocation with subcarriers pairing (SP-PPA); 3. equal power allocation (EPA). The path loss exponent constant $\alpha$is assumed to be 4 and system band is 20 MHz. Without loss of generality, $G_{i,t}G_{i,r}h_{i,t}^2h_{i,r}^2$is normalized to 1.

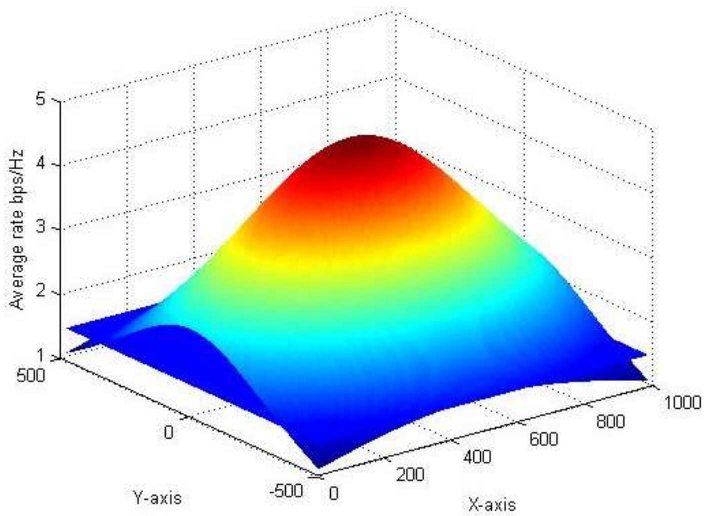

Fig.3. Average rate for PPA scheme and Direct PA scheme, when P_{total} is 10 dBw,M is 2

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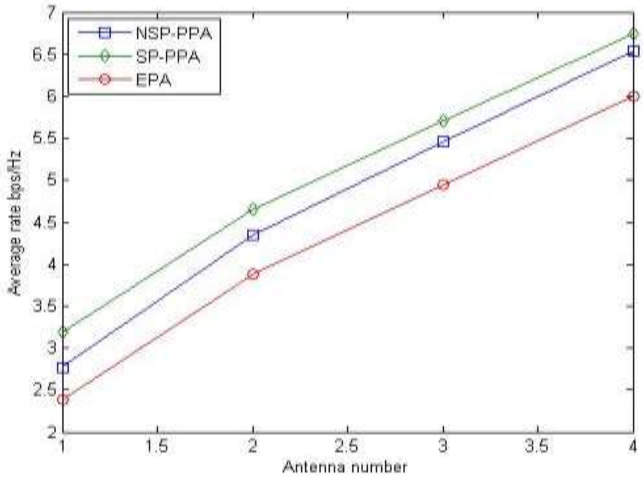

Fig.4. Average rate for three schemes under different antenna number, when d_1 d_1=500m and total transmit power is 10 dBw

In Fig.3, the study area is a 1000×1000 m2 area. The value of X coordinate and Y coordinate indicates the location of RN. The TX and the RX are located at (0, 0) and (1000, 0) respectively. The surface shows the performance for PPA which is described in section III in terms of the average rate, the horizontal plane stands for the reference average rate for the PA without relay scheme. We can see that the average rate for PPA scheme is higher than the second in the most of the study area, especially in the central area, which is called the preferable area. Once the RN is out of the preferable area, the PPA scheme degrades the system performance. It can be used to determine whether the relay should be adopted. If the RN is located in the preferable area, transmit power is allocated to TX and RN according to the PPA scheme; otherwise, the total power is allocated to the TX. It is obvious that the gain reaches its maximum, when the RN is located in the central area.

Fig.4 plots the average rate for three schemes versus the number of antenna equipped at each node. In simulation, we assume that the number of transmitting antenna of the TX node and RN node is equal to the number of receiving antenna of the RN and RX node. It is obvious that NSP-PPA scheme performs better than EPA in MIMO relay channel. And SP-PPA scheme performs better than NSP-PPA.

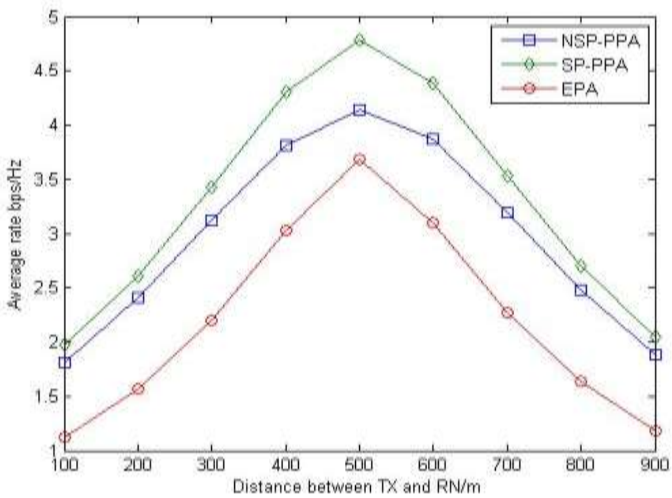

Fig.5. Average rate for three schemes under different distance of the first hop (d_1), when antenna number is 2 and P_{total} is 10 dBw

Fig.5 shows the average rate for three schemes versus the relay's location. From the results, we can conclude that the relay node position has significant impact on the capacity performance of MIMO relay channel. And when RN is located in the middle of TX and RX, SP-PPA scheme can perform much better than other power allocation schemes. But when RN is located close to TX or RX, SP-PPA scheme can not improve the system performance much better than NSP-PPA.

There is no doubt that with the reduction of power, the complexity of the proposed algorithm increases and the performance of the system improves. Fig.6 plots the relation curve between the iterative precision value and the number of iterations, while Fig7 plots the relation curve between the iterative precision value and the average rate, when antenna number is 2 and total transmit power is 10 dBw.

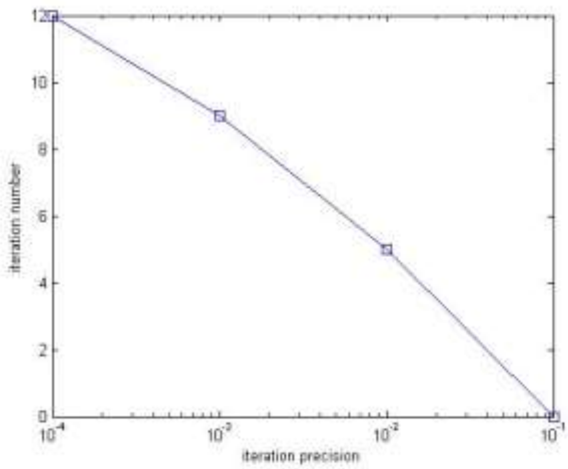

Fig.6.The relation curve between the iterative precision value and the number of iterations, when antenna number is 2 and P_{total} is 10 dBw

From Fig.6, we can know that with the increase of iterative precision, the gradient of the curve gradually decreases. From Fig.7, it can be verified that the better power allocation scheme can be obtained when power tends to be smaller value and average rate will be close to saturated value when power is 10-3w. So it is unnecessary to set up power smaller than 10-3w.

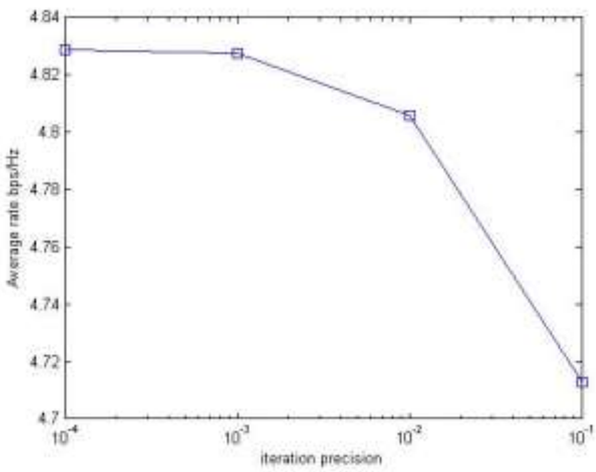

Fig.7.The relation curve between the iterative precision value and the average rate, when antenna number is 2 and P_{total} is 10 dBw

V.CONCLUSIONS

In this paper, a two-hop MIMO-OFDM communication with a transmit node, a receive node and a DF relay is investigated under the assumption that all nodes know accurate instantaneous state information of all channels. Firstly, according to the system model, we derive the formula that indicates how to allocate power for maximum capacity in DF MIMO-OFDM relay system. And then, because it is hard to obtain a general solution expression during deducing, an iterative power allocation algorithm is proposed to achieve the maximum capacity. Moreover, detail simulation analysis is given in this paper.

Numerical results show that by adopting the proposed algorithm, the capacity of MIMO relay channel with DF relay scheme can be significantly improved when RN is located in the preferable area. With the subcarrier pairing strategy before the power allocation, the system capacity can be further improved. Moreover, algorithm complexity of PPA scheme is determined by the value of power. Simulation result shows that 10-3 is low enough to be accepted for practice. Fortunately, capacity gain will be close to saturated value when power is 10-3w. In the future, multi-user fairness power allocation algorithm will be investigated.

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