Novel IDM-Cooperative Diversity Scheme and Power Allocation

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Abstract—In this paper, we propose a novel interleave division multiplexing(IDM) cooperative diversity scheme and we look about some properties of the proposed scheme. The proposed scheme is flexible and has low relay complexity. We also propose a power allocation algorithm. Simulation results show that the proposed scheme achieves diversity gain and the performance is further increased with the proposed power allocations.

Index Terms—Interleave division multiplexing(IDM) cooperative diversity, IDM system, Cooperative diversity, Power allocation.

1. INTRODUCTION

A multiple-input multiple output (MIMO) communication scheme has been studied as an efficient way to combat channel fading. However, wireless devices are limited by size, cost, complexity, and so on to adopt the MIMO technique. Cooperative diversity schemes are proposed as a solution of these limitations [1]-[3]. In these schemes, multiple terminals with single antenna obtain the advantages of the MIMO scheme by sharing their antennas.

When multiple relays exist in the network, each relay use distinct channel such as time slots, frequency bands to separate the signal from each relay. This arouse resource inefficiency. Some resource efficient cooperative diversity schemes are proposed in [4],[5]. However, these schemes are adoptable to the system with specific numbers of relays so as to adopt space-time codes (STC) or quasi-orthogonal space-time codes (QO-STC). In addition, the complexity of relays increase since each of them has to decode the received signal from the source, re-encode, and be controlled the coding-scheme by base station(BS).

In [6],[7], the interleave division multiple access (IDMA) schemes are developed as an alternative system of code-division multiple access (CDMA) systems. In the CDMA systems, the iterative multi-user detection has been studied to mitigate multiple access interference (MAI) and inter-symbol interference (ISI) effectively [8]-[10]. The IDMA system reduces the complexity of MUD and gets spectral efficiency improvements over the CDMA systems [6].

With success of the IDMA systems, an interleave-division multiplexing(IDM) cooperative diversity scheme is proposed recently [11]. In this scheme, the mobiles participate not only as the sources but also as the relays and the mobiles adopt multi-layer concept. This raises burden to the mobiles.

In this paper, we propose a novel IDM cooperative diversity scheme in which the relays have small complexity so that the mobile may well participate in the network. Further, we evolve the signal-to-interference and noise ratio (SINR) which is a key to analyze the performance of the IDMA-based system. Also, we propose a power allocation algorithm to increase the performance.

The rest of this paper is organized as follows. Section II describes the system system model and mentions about the properties. In section III, we evolve SINR and propose the power allocation algorithm. Some simulation results are given in section IV. Section V contains the conclusion.

II. INTERLEAVE DIVISION MULTIPLEXING COOPERATIVE DIVERSITY

In this section, we propose a new class of IDM cooperative diversity. Also, we look about some important properties of proposed scheme.

A. System model

We consider the uplink cooperative system in Fig. 1. The system consists of a source, K relays, and a destination. The signal is transmitted through two phases. For the first phase the source broadcasts the signal to the relays, and the relays transmit their signals for the second phase.

The source generates a input data sequence d = [d(1), d(2),..., d(I)], and it is encoded by a low rate forward error correction (FEC) code to generate a coded sequence c = [c(1), c(2),..., c(J)] where I and J are the number of information bits for a frame and the frame length, respectively. Then the source broadcasts the coded sequence to the relays with power p0. Assume that the channel between the source and each relay is a quasi-static Rayleigh fading channel with additive white Gaussian noise(AWGN).

Each relay regenerates a received sequence yk and the regenerated sequence is permuted by a interleaver πk to an interleaved sequence xk = [xk(1), xk(2),..., xk(J)] where xk(j) is the symbol with power normalized to 1. The interleavers should be different for different relays. Then the relays transmit their interleaved sequence to the destination simultaneously. Assume that the channel between each relay
and destination is a quasi-static Rayleigh fading channel with AWGN.

In the destination, a simple chip-by-chip detection algorithm [6], [7] is adopted. As shown in Fig. 1 (c), the destination consists of an elementary signal estimator (ESE) and a posteriori probability (APP) decoder (DEC). The ESE generate extrinsic log-likelihood ratios (LLRs) $e_{\text{ESE}}(x_k(j))$ under the constraints of the interferences from other relays. The received signal at the destination is given by

$$y_d(j) = \sqrt{p_k} h_{k,d} x_k(j) + n(j) + \zeta_k(j)$$

where $p_k$ is the power of $k$-th relay, $h_{k,d}$ is the channel coefficient between the $k$-th relay and the destination, $n(j)$ is a sample of an AWGN process with zero mean and variance $\sigma^2 = N_0/2$ per dimension, and $\zeta_k(j)$ is the distortion composed of interferences and the noise with respect to the $k$-th relay. Also, the decision variable for $k$-th relay is given by

$$z_k(j) = \text{Re}(h_{k,d}^* y_d(j))$$
$$= \sqrt{p_k} h_{k,d}^* x_k(j) + \text{Re}(h_{k,d}^* \zeta_k(j))$$

where $\text{Re}(\cdot)$ and $\text{Im}(\cdot)$ are the real and imaginary parts, respectively. By the central limit theorem, $\zeta_k(j)$ can be approximated as a Gaussian random variable. Therefore, the PDF of the decision variable can be characterized as a Gaussian distribution. Then, the LLR which is the output of the ESE is given by

$$e_{\text{ESE}}(x_k(j)) = \log \frac{p(z_k(j)|x_k(j) = +1, h_{k,d})}{p(z_k(j)|x_k(j) = -1, h_{k,d})}$$
$$= 2\sqrt{p_k|h_{k,d}|^2 z_k(j) - E[\text{Re}(h_{k,d}^* \zeta_k(j))]}$$

where $E[\cdot]$ and $V[\cdot]$ are the mean and variance functions, respectively. The mean and variance of the distortion term can be obtained as follows [6], [7]:

$$E[\text{Re}(y_d(j))] = \sum_k \sqrt{p_k} \text{Re}(h_{k,d}) E[x_k(j)],$$

$$E[\text{Im}(y_d(j))] = \sum_k \sqrt{p_k} \text{Im}(h_{k,d}) E[x_k(j)],$$

$$V[\text{Re}(y_d(j))] = \sum_k p_k |\text{Re}(h_{k,d})|^2 V[x_k(j)] + \sigma^2,$n

$$V[\text{Im}(y_d(j))] = \sum_k p_k |\text{Im}(h_{k,d})|^2 V[x_k(j)] + \sigma^2,$$

$$E[\text{Re}(h_{k,d}^* \zeta_k(j))] = \text{Re}(h_{k,d}) E[\text{Re}(y_d(j))] + \text{Im}(h_{k,d}) E[\text{Im}(y_d(j))]$$
$$- \sqrt{p_k|h_{k,d}|^2 E[x_k(j)]},$$

$$V[\text{Re}(h_{k,d}^* \zeta_k(j))] = |\text{Re}(h_{k,d})|^2 V[\text{Re}(y_d(j))]$$
$$+ |\text{Im}(h_{k,d})|^2 V[\text{Im}(y_d(j))]$$
$$+ 2 \text{Re}(h_{k,d}) \text{Im}(h_{k,d}) \psi(j)$$
$$- p_k|h_{k,d}|^2 E[x_k(j)],$$

where $\psi(j) = \sum_k \sqrt{p_k} \text{Re}(h_{k,d}) \text{Im}(h_{k,d}) V[x_k(j)]$ is the covariance of $\text{Re}(h_{k,d})$ and $\text{Im}(h_{k,d})$.

Since $x_k$ is a replica of $\zeta$, we collect the related LLRs. The deinterleaved version of the output of ESE $\pi^{-1}(e_{\text{ESE}}(x_k(j)))$ is concerned with $e(j)$. So we collect the LLRs as

$$e_{\text{ESE}}(e(j)) = \sum_k \pi^{-1}(e_{\text{ESE}}(x_k(j))) + e(j).$$

Then it becomes the input to the DEC. The DEC applies the standard APP decoding [12], [13] to produce extrinsic LLRs $e_{\text{DEC}}(d(j))$ under the constraints of the FEC. This sequence is copied $K$ times and each sequence is interleaved to the sequence $e_{\text{DEC}}(x_k(j))$. This sequence is used to generate the following statistics

$$E[x_k(j)] = \tanh \left( \frac{e_{\text{DEC}}(x_k(j))}{2} \right),$$

$$V[x_k(j)] = 1 - E[x_k(j)]^2.$$
and operations are carried out iteratively. After the iterations of pre-defined number \( I \), the DECs determine the estimate of the information bit \( \hat{d}(i) \).

B. Properties

Even if the number of relays is changed, the operations of the source, the relays, and the destination are not changed. This means that the proposed scheme has the flexibility in terms of the number of relays. It allows the employment of an arbitrary number of relays in the system. So if some mobile stations want to join or disjoin the system, they can freely. This flexibility make forming a cooperative system easy. Therefore, the proposed scheme can be adaptable in various network scenarios [11].

Also, the proposed scheme doesn’t cause resource inefficiency and the complexity of the relays are low compared to other cooperative diversity schemes. In many cooperative diversity schemes, each relay uses its distinct channel (time slot, frequency bands, and so on) and it causes resource inefficiency. Or, to make the channel uses to be common (e.g., slot, frequency bands, and so on) and it causes resource inefficiency. So, the mobiles can act as a relay since it is not a large burden.

From the properties, we notice that this scheme is available to the practical mobile network.

III. SINR EVOLUTION AND POWER ALLOCATION

In this section, we derive the SINR and propose a power allocation algorithm.

A. SINR evolution

The expected signal power of the \( k \)-th relay is given by

\[
E[S_k] = p_k|h_{k,d}|^2\{1 - g(h_{s,k}, p_0)\} - p_k|h_{k,d}|^2g(h_{s,k}, p_0) = p_k|h_{k,d}|^2\{1 - 2g(h_{s,k}, p_0)\}
\]

where \( g(h_{s,k}, p_0) \) is the bit error probability (BER) at the \( k \)-th relay when \( h_{s,k} \) and \( p_0 \) are given. Also, the expected interference power of the \( k \)-th relay with respect to the \( l \)-th relay is given by

\[
E[I_{k,l}] = p_l|h_{l,d}|^2(f(\gamma)\{1 - 2g(h_{l,k}, p_0)\} + p_l|h_{l,d}|^2\{1 + (1 - f(\gamma))\})g(h_{l,k}, p_0)
\]

where \( f(\gamma) \) is the expected value of \( V[x_k(j)] \) at the DEC when the SINR \( \gamma \) is given. The expected signal power is independent to the expected interference power. So, the expected SINR of \( i \)-th iteration is given by (16).

For simplicity, we introduce

\[
q_k = p_k|h_{k,d}|^2\{1 - 2g(h_{s,k}, p_0)\}.
\]

Then, the SINR can be rewritten as

\[
\gamma_i = \sum_k \frac{q_k}{\sum_{k \neq l} q_l f(\gamma_{l-1}) - q_l + p_l|h_{l,d}|^2} + \sigma^2.
\]

B. Problem formulation

The aim of power allocation is to achieve maximum SINR where the total power is given. The power allocation problem is formulated as

\[
\{p_k\} = \arg \max_{\{p_k\}} \gamma_l
\]

Subject to \( \sum_k p_k \leq P_T \)

\[
p_k \leq P_{k,max} \quad \forall k
\]

where \( P_T \) is the total usable power for the relays and \( P_{k,max} \) is the maximum power that the \( k \)-th user can use. This problem is complex due to the iterations. So, for simplicity, we assume the convergence of the interference by introducing a decay factor \( \delta \). Then we obtain the problem as

\[
\{q_k\} = \arg \max_{\{q_k\}} \gamma
\]

Subject to \( \sum_k q_k f(\gamma_l) \leq \delta \sum_k q_k f(\gamma_{l-1}) \)

\[
\sum_k p_k \leq P_T
\]

where

\[
\gamma = \sum_k \frac{q_k}{\sum_{l \neq k} \{-q_l + p_l|h_{l,d}|^2\} + \sigma^2}.
\]

C. Power allocation algorithm

Assume that the base station feed back \( m \)-bit to the relays for power allocation. Then, the power level should be defined represented with \( L = 2^m \) levels. We quantize the values \( q_k \) into \( L \) discrete values \( q(l), l = 1, 2, \ldots, L \) to satisfy

\[
q(1) < q(2) < \cdots < q(L) = \max_k q_k.
\]

Let \( \phi(l) \) denote the number of relays assigned to power level \( q(l) \). Also, let the maximum value of \( \phi(l) \) considering the channel coefficient and \( P_{k,max} \) as \( \max \phi_{max}(l) \). Then the constraints become

\[
\phi(l) \leq \phi_{max}(l)
\]

\[
\sum_l \phi(l) = K
\]

\[
\sum_l \phi(l)q(l)f(\gamma_l) \leq \delta \sum_l \phi(l)q(l)f(\gamma_{l-1})
\]

We can find the solution of this problem easily by linearization technique [14], [15] and fine the distribution of \( \{q_k\} \).

However, we have to find the distribution of \( \{p_k\} \). The algorithm to find the distribution of \( \{p_k\} \) is described in algorithm 1.
Algorithm 1: Power allocation algorithm

Initialization:
Initialize $K = \{1, 2, \ldots, K\}$ and $Q = \{\tilde{q}_1, \tilde{q}_2, \ldots, \tilde{q}_K\}$
where $\{\tilde{q}_k\}$ is re-ordered version of $\{q_k\}$ such that
$\tilde{q}_1 \leq \cdots \leq \tilde{q}_K$.
Initialize $q_k = 0, \forall k$.
Initialize $\lambda_k = |h_{k,d}|^2\{1 - 2g(h_{s,k}, p_0)\}$.

Power allocation algorithm:
While $Q \neq \emptyset$ do
    $k' = \arg\max_k \lambda_k$
    $j = n(Q)$
    while $q_{k'} = 0$ do
        if $q_j \leq \lambda_{k'}/P_{k',\text{max}}$ then
            $p_{k'} = \frac{q_j}{\lambda_k}$
        else
            $j = j - 1$
        end while
    $K = K - \{k'\}$, $Q = Q - \{q_j\}$
end for

IV. NUMERICAL RESULTS

In this section, we demonstrate the performance of the proposed IDM cooperative systems. Assume that the source uses a half rate convolutional code $(23, 35)_8$ as a FEC. Suppose that the number of information bits in a frame $I$ is 128, the variances of the channel coefficients of both $h_{s,k}$ and $h_{k,d}$ are all 0.5 per dimension.

Fig. 2 shows the BER versus $P_T$ of the proposed systems for various numbers of relays and iterations. We assume equal power allocation. For comparison, the BER of the systems which the relays use orthogonal channels is also shown. It is well known that we can obtain full diversity with orthogonal channels. From the results, the performances converge to cases of orthogonal channels after some iterations - it is enough with 3 iterations. The error floor phenomenon occurs since the performance is affected by $p_0$ more than by noise at high SNR region.

Fig. 3. shows the BER of the proposed system with the proposed power allocation. We assume 3 iterations and $P_{k,\text{max}} = \frac{1}{2}P_T$ for all $k$. From the results, it is shown that the BER is further decreased with the proposed power allocation algorithm.

V. CONCLUSION

In this paper, we propose a novel IDM cooperative diversity and we look about some properties of the proposed scheme. The proposed scheme is flexible and has low relay complexity. We also propose a power allocation algorithm. Simulation results show that the proposed scheme achieves diversity gain and the performance is further increased with the proposed power allocation.

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Fig. 3. Bit error rate for proposed power allocation

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