Cooperative Diversity Technique
Using Spatial Phase Coding Based on OFDMA System

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Introduction

Wireless Communication

- Recently, data traffic is rapidly increasing
- In order to meet the capacity demand, many digital communication systems have been studied

Multiple-Input Multiple-Output (MIMO) System

- A MIMO technology provide high-speed data transmission by using multiple transmit and receive antennas without the additional bandwidth.
- MIMO systems suffer the problems of high cost, size and the high power consumption of remote units.

Cooperative Communication

- To overcome the disadvantages of the MIMO system, cooperative communication has been studied
- But, it has a common problem of decreased transmission rate
Orthogonal Frequency Division Multiple Access (OFDMA)

- It can achieve multi-user diversity by designing the subcarrier allocation.
- OFDMA system consists of $N$ subcarriers and $M$ active users.
- $K = \frac{N}{M}$ is the number of subcarriers assigned to each user.

<OFDMA transmission sequence>

Frequency band for first user

Frequency band for $M$-th user

$X^1$ $X^2$ \ldots $X^M$

$K$

$N$

<OFDMA transmission sequence>
Spatial Phase Coding (SPC)

SPC is pre-coding scheme using feedback information.
The concept of SPC is to selectively flip channels between transmitter and receiver.
Superposed the selectively flipped channels.
Criterion for state change is defined as follows

\[
F^k = \begin{cases} 
\text{no state change} & |\alpha^k| \leq \frac{\pi}{2} \\
\text{state change} & \frac{\pi}{2} < |\alpha^k| \leq \pi 
\end{cases}
\]

Pre-coding vector for 1-bit feedback SPC

\[
P^k_1 = \frac{1}{\sqrt{2}}, \quad P^k_2 = \begin{cases} 
\frac{1}{\sqrt{2}} & \text{state 1} \\
\frac{1}{\sqrt{2}} e^{-j\pi} & \text{state 2}
\end{cases}
\]
Spatial Phase Coding (cont’d)

Principle of spatial phase coding with angle criterion

\[ H_n = H_{u(j),b} + H_{u(i),b} \]

- a) No phase flipping (State 1)
- b) Phase flipping (State 2)
Proposed System Model (1)

Proposed Cooperative System Model

- The system consists of two users which have a single antenna and a base station which has a single antenna.
- \( H_{u(i),u(j)} \) and \( H_{u(j),u(i)} \) are inter-user channels from the \( i \)-th user to the \( j \)-th user and from the \( j \)-th user to the \( i \)-th user.
- \( H_{u(i),b} \) and \( H_{u(j),b} \) are uplink channels from the \( i \)-th user to base station and from the \( j \)-th user to base station.

<Proposed system model>
Assumption of Proposed Cooperative OFDMA System

- The system is supposed to the full-duplex channel
- The channels are assumed to be constant during one time slot
- Channel condition on communication link of the proposed system is estimated entirely at receiver
Proposed Cooperative Scheme (1)

Proposed Cooperative Scheme

- Cooperative communication technique using SPC based on OFDMA System
- The proposed scheme can avoid rate-loss and obtain diversity gain

Proposed Cooperation Scheme Process

- Users search the best partner among several candidates
- The users transmit the own signal with BPSK modulation
- The received signal is estimated with DF method
- The estimated signal and own signal are recomposed
- The recomposed signal is coded with feedback information and is transmitted to base station
- The transmitted signal is modulated with QPSK modulation
- The base station estimated the received symbol without additional process
Proposed Cooperation Scheme Process (cont’d)

At time slot 1, the users transmit the own signal with BPSK modulation

The received the $l$-th signal at each user is as follows

\[ R^{(i)}(l) = X^{(j)}(l) \cdot H_{u(j),u(i)} + \eta \]
\[ R^{(j)}(l) = X^{(i)}(l) \cdot H_{u(i),u(j)} + \eta \]

- $X^{(m)}(l)$: $l$-th transmission information of the $m$-th user ($m = i, j$)
- $\eta$: a complex Gaussian random variable with zero mean and variance of $\sigma^2$

The received signal is estimated to $\hat{X}^{(m)}(l)$ with DF method.

At time slot 2, the each of the users transmits own signal $X^{(j)}(l + T)$ and $X^{(j)}(l + T)$ to partner by frequency band of partner.

At the same time, the estimated signal and the own signal are recomposed with QPSK modulation.
Proposed Cooperation Scheme Process (cont’d)

- The recomposed signals are coed with 1-bit feedback SPC and are transmitted to base station by each own frequency band.

- The received signal at base station is as follows

\[
Y(l) = \begin{bmatrix} P_m \cdot X^{(i,j)}(l) & P_m \cdot X^{(i,j)}(l) \end{bmatrix} \begin{bmatrix} H_{u(i),b} \\ H_{u(j),b} \end{bmatrix} + N
\]

- \( X^{(i,j)}(l) \): recomposed signal with data of the \( i \)-th user and the \( j \)-th user
- \( P_m \): pre-coding vector (\( m = i, j \))
- \( X^{(m,n)}(l) \): transmit signal
- \( N \): a complex Gaussian random variable

\[
\hat{X}^{(i,j)}(l) = \frac{Y(l)}{H_n} + N
\]
Proposed Cooperation Scheme Process (cont’d)

- The estimated signal is written as
  \[ \hat{X}^{(i,j)}(l) = Y(l)/H_n + N \]
- \[ H_n = P_m \cdot H_{u(j),b} + P_m \cdot H_{u(i),b} \]
- The receiver estimates the received symbol without additional process
- The transmission steps of the propose scheme

<An example of the proposed scheme for OFDMA system>

<table>
<thead>
<tr>
<th>Time slot</th>
<th>Frequency band for i-th user</th>
<th>Frequency band for j-th user</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i-th user</td>
<td>j-th user</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>( X^{(j)}(1) )</td>
</tr>
<tr>
<td>2</td>
<td>( P_m \cdot X^{(i,i)}(1) )</td>
<td>( X^{(j)}(2) )</td>
</tr>
<tr>
<td>3</td>
<td>( P_m \cdot X^{(i,i)}(2) )</td>
<td>( X^{(j)}(3) )</td>
</tr>
<tr>
<td>4</td>
<td>( P_m \cdot X^{(i,i)}(3) )</td>
<td>( X^{(j)}(4) )</td>
</tr>
<tr>
<td>( \vdots )</td>
<td>( \vdots )</td>
<td>( \vdots )</td>
</tr>
<tr>
<td>1</td>
<td>( P_m \cdot X^{(j,i)}(l-1) )</td>
<td>( X^{(j)}(l) )</td>
</tr>
</tbody>
</table>
Simulation Result (1)

Parameter
- 7-path Rayleigh fading channel
- Subcarrier = 512
- Guard Period = 128
- Convolution code with rate = $\frac{1}{2}$ and constraint length = 7

Conventional Schemes
- $2 \times 1$ cyclic delay diversity (CDD)
- $2 \times 1$ spatial phase coding (SPC)
- $2 \times 1$ maximum ratio transmission (MRT)
BER performance

Compared with multiple antenna schemes

SNR_D is set to 0 and 5dB
BER performance

Compared with cooperative scheme based on OFDMA of other letter
- An improved transmission rate in cooperative communication based on OFDMA system (Transmit Rate = 3/4)
- SNR_D is set to 0, 5 and 10dB
Throughput performance

- Compared with cooperative scheme based on OFDMA of other letter
  - SNR_D is set to 10dB
  - Throughput = \((1 - BER) \cdot Transmit \ rate \cdot Symbol \ rate\)
Simulation Result

- Compared with multiple antenna schemes
  - The performance of proposed cooperative scheme is always higher than cyclic delay diversity (CDD) with 2 1 antennas
  - Although the performance of proposed cooperative technique is lower than maximum ratio transmission (MRT), the proposed cooperative scheme requires a small feedback information than MRT
  - If the SNR D is guaranteed, the BER performance of the propose scheme is improved.

- Compared with cooperative scheme based on OFDMA of other letter
  - A BER performance of the proposed scheme is better than the another cooperative scheme
  - Throughput of the proposed scheme is higher than the another cooperative scheme
Although, the propose scheme requires feedback information, the required information is only 1-bit or 2-bit.

Simulations shows that the proposed cooperative scheme has better BER performance and transmission rate than conventional cooperative scheme.

It is expected that high performance without transmission loss can be attained in wireless communication system.
Thank you for giving your attention!