Bit Error Performance of PLNC based SSK Modulated Bidirectional Relay Network in Rayleigh Fading Channel

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Abstract—Bidirectional relay communication has attracted the research community due to its high bandwidth efficiency. Space Shift Keying (SSK) modulation is a promising Multiple-Input–Multiple-Output (MIMO) technique in which only a single antenna is activated for transmission at any time instant and the index of this active antenna is used to convey information. In this paper, Physical Layer Network Coding (PLNC) based bidirectional relay network using SSK modulation is proposed in Rayleigh fading environment. A bidirectional Decode and Forward (DF) relay network consists of two source nodes and a relay node and it operates in a half duplex mode. Specifically, the transceiver at source nodes and relay node sends the data by employing SSK modulation and detects the signal based on the Maximum Likelihood (ML) detection criterion. The error performance of PLNC protocol in bidirectional DF relay networks for SSK is analyzed in a fading environment. The Pair-wise Error Probability (PEP) is derived at the relay node and source nodes in closed form. The end-to-end PEP is also derived in closed form. The analytical results are verified using simulations.

Index Terms - Bidirectional DF relay network, Physical Layer Network Coding, Pair-wise Error Probability and Space Shift Keying

I. INTRODUCTION

SSK is one of the MIMO techniques and it is used in an energy efficient future wireless networks. It was first introduced in [1] as a space modulation technique to improve the performance of wireless networks. It is the simple form of spatial modulation (SM) which is analyzed in [2] and [3]. Specifically, SSK is primarily used due to its low detection complexity and simple transceiver structure. The principle of the SSK is based on distinct multipath nature of different antennas on a wireless fading environment. The receiver in SSK utilizes the distinct received signals from different antennas to discriminate the transmitted messages, which results in simple receiver complexity [4] and [5].

Bidirectional relay network is used in intra cell, intra hotspot and intra picocell communication. It is used to exchange the information among two source nodes with the help of a relay node using PLNC protocol in two phases, namely multiple access relaying phase and broadcasting phase. In the first phase, two source nodes transmit simultaneously their signals to a relay node over a Multiple Access Channel (MAC). In broadcasting phase, the relay node broadcasts the XORed version of the two received signals to the two source nodes over a Broadcast Channel (BC). The error performance of the PLNC protocol is analyzed in bidirectional relay networks for BPSK modulation over Rayleigh fading channels using Maximum-Likelihood (ML) detection metric at the relay with the max-log approximation [7]. The limited feedback technique into (PLNC scheme is introduced in [11] using Decode-and-forward (DF) and partial-decode-and-forward (PDF) strategies are considered along with Alamouti’s orthogonal space–time block code to provide diversity and to increase the bit error rate (BER) performance.

The contributions of this paper are as follows: i) A PLNC based bidirectional DF relay network with SSK modulation in a fading environment is proposed. ii) A closed form expressions for the PEP of the source to relay, relay to source and the overall system are derived and the analytical findings are substantiated by Monte Carlo simulations. This paper is organized as follows: Section II presents the proposed system model of PLNC based DF bidirectional relay network using SSK modulation in the Rayleigh fading channel. Section III and IV analyzes the communication strategy between source to relay and relay to source respectively using optimal ML detection scheme. Simulation results are discussed in Section IV and Section V concludes the paper.
II. SYSTEM MODEL

Consider a bidirectional DF relay network shown in Figure 1 with the relay node R between two source nodes $S_1$ and $S_2$. The relay node assists in exchange of data between the source nodes using the concept of PLNC. Each node in this network is assumed to have two antennas and operates in half-duplex mode. $H$ and $G$ denote the $2 \times 2$ channel matrices between the source node $S_1$ & relay node R, and source node $S_2$ & relay node R respectively.

\[
\begin{align*}
\text{Time Slot 1} & \rightarrow \quad H \rightarrow \quad R \rightarrow \quad G \\
\text{Time Slot 2} & \rightarrow \quad S_1 \rightarrow \quad H \rightarrow \quad R \rightarrow \quad S_2
\end{align*}
\]

Fig. 1. Bidirectional DF Relay Network with SSK

In a Rayleigh fading environment, $H$ and $G$ have independent and identically distributed (iid) entries according to $CN(0,1)$.

III. SOURCE NODE TO RELAY COMMUNICATION

In time slot I, both source nodes send data to relay node. Since, at a time, only one antenna is activated at each source node, the $2 \times 1$ received signal vector at relay node R is given by,

\[
y_R = \sqrt{\rho} H x_1 + \sqrt{\rho} G x_2 + n.
\]  

(1)

where $H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$, $G = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}$, $x_1$ and $x_2$ belong to the set $\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$. $\rho$ is the average SNR at each receive antenna, $H$ and $G$ are $2 \times 2$ channel matrices with its elements are independent and identically distributed random variables with zero mean and unit variance and $n$ is a $2 \times 1$ vector with elements which are independent and identically distributed random variables with zero mean and unit variance. Since $x_1$ and $x_2$ contain only one non-zero element, Equation (1) can be expressed as, Equation (1) can be expressed as,

\[
y_R = \sqrt{\rho} h_{i1} + \sqrt{\rho} g_{j1} + n.
\]  

(2)

Given $H$ and $G$, Maximum Likelihood detection criterion is applied at relay node R to detect the signal. The received signal is the noise corrupted sum of the power of the signals from two source nodes. The ML-detection at the relay node R is denoted as,

\[
[i, j] = \min_{i \in (1,2), j \in (1,2)} \left\{ \left\| y_R - \sqrt{\rho} (h_{i1} + g_{j1}) \right\|_2^2 \right\}.
\]  

(3)

The estimation of the antenna index can also be written as,

\[
[i, j] = \arg \max_{i \in (1,2), j \in (1,2)} \mathbb{R} \left\{ y_R - \frac{\sqrt{\rho}}{2} (h_{i1} + g_{j1})^H (h_{i1} + g_{j1}) \right\}.
\]  

(4)

where $\mathbb{R}\{ \cdot \}$ denotes the real part of the signal.

A. Error Performance Analysis at Relay node

Let $PEP_e$ denote the pair wise error probability (PEP) at the relay node for the given $H$ and $G$ is given by,

\[
PEP_e = \frac{1}{4} \left[ P((i, j) \rightarrow \hat{i}, \hat{j}) + P((i, j) \rightarrow \hat{i}, \hat{j}) \right].
\]  

(5)

where $P((i, j) \rightarrow \hat{i}, \hat{j})$ denotes the PEP of deciding on the antenna index $\hat{j}$ given that index $j$ is selected. Let $PEP_{eR} = P((i, j) \rightarrow \hat{i}, \hat{j})$ and $PEP_{eL} = P((i, j) \rightarrow \hat{i}, \hat{j})$.

From (4) and (5),

\[
PEP_{eR} = P(Z > \sqrt{\frac{\rho}{2}} \left\| g_{j1} - g_{j1} \right\|^2).
\]  

(6)

Let $Z = \mathbb{R}\{ H (g_{j1} - g_{j1}) \}$ is a Gaussian random variable with zero mean and variance $\frac{1}{2} \left\| g_{j1} - g_{j1} \right\|^2$.

\[
PEP_{eL} = P\left( Z > \sqrt{\frac{\rho}{2}} \left\| g_{j1} - g_{j1} \right\| \right).
\]  

(7)

It can be expressed in terms of $Q(.)$ function as,

\[
PEP_{eL} = Q\left( \sqrt{\frac{\rho}{2}} \left\| g_{j1} - g_{j1} \right\| \right).
\]  

(8)

where $Q(y) = \frac{1}{\sqrt{2\pi}} \int_{y}^{\infty} e^{-\frac{t^2}{2}} dt$ and $y$ is defined as,
The average bit error probability for SSK at relay node $R$ is derived from the union bounding technique [8] and it is union bounded as,
\[
P_e^R \leq 2 \left( \gamma' \right)^2 \sum_{k=0}^{\infty} \left( 1-\gamma' \right)^k
\]
(17)

IV. RELAY TO SOURCE COMMUNICATION

In time slot II, broadcasting phase occurs, in which R broadcasts its signal to $S_1$ and $S_2$.

Let $x_\ell \in \left[ \begin{array}{c} 1 \\ 0 \\ 1 \end{array} \right]$ be the symbol to be broadcast from relay node to source nodes $S_1$ and $S_2$ using SSK modulation as shown in Table.1. Under the assumption that the channel from relay node R to $S_1$ and $S_2$ is quasi-static, the signal received by $S_1$ and $S_2$ is given respectively by,
\[
y_1 = \sqrt{\rho}h_1 + n_1
\]
(18)
\[
y_2 = \sqrt{\rho}g_j + n_2
\]
(19)
where $n_i, i=1,2$ is the noise vector at i-th source node $S_i$ with $n_i \sim CN(0,1)$. The ML detection at $S_i, i=1,2$ for the symbol broadcasted by the relay node, $x_\ell$ can be written as,
\[
i = \arg \min_{i=1,2} \| y_{S_i} - \sqrt{\rho}h_i \|^2
\]
(20)
The estimation of the antenna index at $S_i, i=1,2$ can be written as,
\[
i = \arg \max_{i=1,2} g_R \left( y_{S_i}, \sqrt{\rho}h_i \right)^H h_i
\]
(21)

A. Error Performance Analysis at Source nodes

Let $PEP_{S_i} = P(\ell \rightarrow i) ||H||$ and $PEP_{R_i} = P(j \rightarrow j) ||G||$

Similar to the analysis from the above section, the closed form expression for average PEP at $S_i, i=1,2$ is given by,
\[
PEP_{Avg} = \gamma' \sum_{k=0}^{\infty} \left( 1-\gamma' \right)^k
\]
(22)
The average bit error probability for SSK at
The theoretical BER performance at the relay node of the proposed system agrees well with the simulation results.

Fig. 2. BER of the proposed bidirectional Relay Network

V. CONCLUSION

The PLNC based bidirectional DF relay network with space shift keying modulation for Rayleigh fading wireless environment is proposed. Currently, communication using bidirectional DF relay network has received considerable attention due to the high bandwidth efficiency. The closed form expressions for the bit error probability for the source nodes to relay node in time slot I, relay node to source nodes in time slot II and the overall end-to-end system are derived and compared with the simulation results. Bidirectional relay network is useful for intra cell, intra hotspot and intra picocell communication and an energy efficient next generation wireless networks.

REFERENCES
