Incremental Hybrid DAF Scheme based Cooperative Spatial Modulation

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Abstract—**In this paper, we propose a cooperative spatial modulation (SM) system combined with incremental hybrid decode-amplify-forward (IHDAF) scheme, which can select direct transmission or the corresponding relaying protocol according to the instantaneous channel signal-to-noise ratio (SNR). The signal processing scheme has also been provided. Simulation results of the system outage probability show that the proposed cooperative SM system with IHDAF scheme outperforms the conventional cooperative SM systems, such as amplify-and-forward (AF) based SM and decode-and-forward (DF) based SM. Furthermore, the influence of the relay location and power allocation factor on the outage probability performance has also been investigated for the IHDAF based cooperative SM system.**

Keywords—cooperative spatial modulation; IHDAF; outage probability; power allocation factor; relay location

I. INTRODUCTION

The requirements of high date rate and better transmission performance attract more and more researchers to seek new transmission technologies. Spatial modulation (SM), as an extension of multiple-input multiple-output (MIMO) [1] technology, which utilizes the index of the transmit antennas to obtain extra improvement in the information transmission rate has been proposed. Conventional SM explores the characteristics of MIMO technology and reduces the problems in MIMO system, such as the inter-channel interference (ICI), inter antenna synchronization (IAS) and so on, by activating only one transmit antenna [2][3]. As a widely studied special simple case of SM technology, space shift keying (SSK) conveys only the spatial domain information bits which determine the transmit antenna index to the destination node [4].

Cooperative communication, originated also from MIMO technology, provides transmit diversity, increased coverage area, and improved system performance [5][6]. Many lectures have studied the classical cooperative protocols, such as amplify-and-forward (AF) protocol, decode-and-forward (DF) protocol, incremental relaying protocol and so on [7]-[9]. Considering the characteristics of cooperative technology, it has been introduced in SM system to obtain the advantages of cooperation. N. Serafimovski, *et al* in [10] proposed a dual-hop spatial modulation scheme to get significant improvements in spectral efficiency and coding gains by increasing the number of the transmit antennas of the source node and the relay node compared with the non-cooperative DF system. An AF relaying scheme in dual-hop SSK system has been proposed in [11], where the simulation results and analysis validate the improved system performance due to the cooperative technology. In [12][13], a best relay selection scheme in SSK system has been investigated. The authors in [12] selected the best relay based on the available signal-to-noise ratios (SNRs) at the destination and employed AF protocol to transmit the signal from the relay to the destination. The bit error rate (BER) expression of this scheme has been provided. In [13], a threshold-based best relay selection scheme in SSK systems with DF protocol was studied, which performs selection combining among the direct and relaying paths at the destination, and an exact analytical expression of the closed-form end-to-end average bit error probability (ABEP) is derived.

Different from the bit error rate (BER) performance analysis, the outage probability analysis of the cooperative SM system has been evaluated in [14], where the authors presented the outage probability considering different relaying protocols and achieved a better performance compared with the conventional SM systems. Based on the aforementioned research work, we take the relaying protocol selection scheme, incremental hybrid DAF (IHDAF) scheme proposed by Z. Bai *et al* in [15], into consideration and proposed an IHDAF protocol based cooperative SM system in this paper. The proposed scheme takes the advantages of both the SM and IHDAF schemes to improve the system performance. The corresponding signal processing scheme and simulation results have been provided, which show the significant improvement in the system outage probability compared with the conventional AF or DF based cooperative SM schemes.

The rest of this paper is organized as follows. In Section II, we present the system model of the IHDAF protocol based cooperative SM system and the corresponding signal processing algorithm. Simulation results and performance analysis of the proposed IHDAF scheme based cooperative SM system have been provided in Section III to show the efficiency of the proposed scheme compared with the conventional AF or DF based cooperative SM scheme. Finally, Section IV concludes this paper.

II. IHDAF PROTOCOL BASED SM SYSTEM

In this paper, a typical three node cooperative spatial modulation system is considered. As shown in Figure 1, the

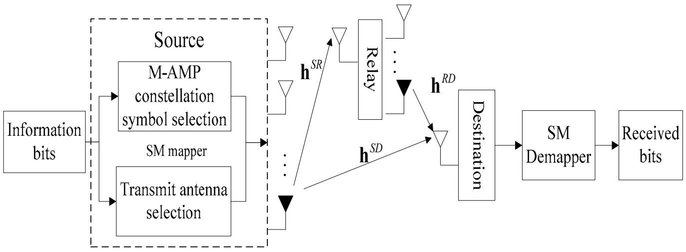

Figure 1. IHDAF based cooperative SM system model.

source node (S) and the relay node (R) are equipped with N_t=2^m transmit antennas. The relay R and the destination node (D) are equipped with single receive antenna. The information bits in the source node are grouped into two parts at the SM mapper, the first $\log_2(N_t)$ bits are used to select the transmit antenna and the following $\log_2(M)$ bits are utilized to select the constellation symbol. Then, the symbol is transmitted to both R and D over the activated antenna. For the relay node R, it will first recover the received signal from S and re-encodes the recovered signal with the same SM scheme in the case of DF protocol, or it will amplify the received signal and forwards it to D for the AF protocol. Considering both the direct transmission and the corresponding relaying protocol at R, D will combine the received signals from S and R together and make the detection with maximum likelihood (ML) algorithm. It is assumed that perfect channel state information (CSI) can be obtained at the relay node and the destination node with training sequences. We denote the source to destination (S-to-D), source to relay (S-to-R) and relay to destination (R-to-D) channel vectors as $\mathbf{h}^{SD}$, $\mathbf{h}^{SR}$ and $\mathbf{h}^{RD}$, respectively, which all obey the flat Rayleigh fading distribution.

At the transmitter, the information bits are grouped and input to the SM mapper which maps the grouped information bits according to the number of the transmit antennas and activates only one of the transmit antennas. Following the same notation in SM, the SM symbol vector with unit energy $E[\mathbf{x}^H\mathbf{x}]=1$ in our scheme can be expressed as,

$$\mathbf{x}=[0,0,...,0,\underset{\substack{\uparrow \\ l^{th}\,coordinate}}{x_q},0,...,0]^T, \quad (1)$$

where l is the active antenna index and x_q is the unit energy amplitude and phase modulation (APM) symbol.

The system communication process of the proposed IHDAF based SM scheme can be shown in Figure 2. At the first time slot, the source S broadcasts the transmitted signal to both the relay R and the destination D at the same time. The received signal at the R and D can be written respectively as,

$$y^{SR}=h_l^{SR}x_q+n^{SR} \quad (2)$$

$$y^{SD}=h_l^{SD}x_q+n^{SD}, \quad (3)$$

where h_l^{SD} and h_l^{SR} denote the l^{th} element of the channel vector $\mathbf{h}^{SD}$ and $\mathbf{h}^{SR}$, respectively. n^{SD} and n^{SR} are the additive white Gaussian noise (AWGN) for the S-to-D channel and S-to-R channel with a double-sided power spectral density $N_0/2$. The corresponding instantaneous SNRs of the S-to-D, S-to-R and

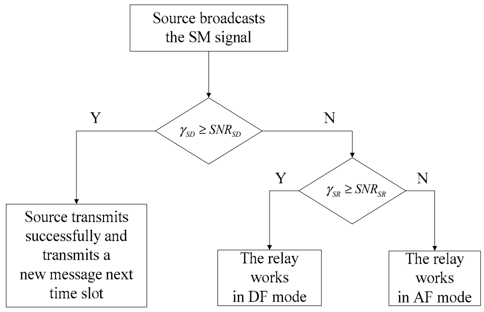

Figure 2. Communication process of the IHDAF based cooperative SM system.

R-to-D links can be written respectively as,

$$\gamma_{SD}=|h_l^{SD}|^2\,P_S/N_0 \quad (4)$$

$$\gamma_{SR}=|h_l^{SR}|^2\,P_S/N_0 \quad (5)$$

$$\gamma_{RD}=|h_{\tilde{l}}^{RD}|^2\,P_R/N_0\ , \quad (6)$$

where $\tilde{l}$ is the transmit antenna index of the relay node and $|\cdot|$ represents the absolute value. $P_S=\delta P$ and the $P_R=(1-\delta)P$ are the transmission power of the source and the relay, respectively, and P is the total system power with power allocation factor $\delta\in(0,1]$ assigned for the source node S.

After receiving the transmitted signal, the destination D will compare the instantaneous channel SNR γ_{SD} with the pre-determined threshold SNR_{SD} to judge whether it can recover the signal from the source S correctly or not. If γ_{SD} is larger than the threshold SNR_{SD}, the direct transmission will be taken and the source S will transmit a new signal at the next time slot. The ML detector at the destination D can be derived as,

$$[\hat{l},\hat{x}_q]=\arg\min_{l,x_q}\left\|y^{SD}-h_l^{SD}x_q\right\|^2. \quad (7)$$

Otherwise, the relay R will be chosen to forward the signal to the destination D. Before forward the signal from R to D, the relay R will compare the instantaneous channel SNR γ_{SR} with the pre-determined threshold SNR_{SR} to select which protocol will be employed. If γ_{SR} is larger than SNR_{SR}, R will process the signal with ML detection and make a decision according to the following equation

$$[\tilde{l},\tilde{x}_q]=\arg\min_{l,x_q}\left\|y^{SR}-h_l^{SR}x_q\right\|^2. \quad (8)$$

After the signal recovery, the relay will re-encode the recovered signal to a new SM signal and sends it to D at the second time slot. The received signal at the destination D with DF protocol can be expressed as,

$$y_{DF}^{RD}=h_{\tilde{l}}^{RD}\tilde{x}_q+n^{RD}. \quad (9)$$

If γ_{SR} is no larger than SNR_{SR}, then AF relaying protocol will be employed by R. In this case, R just amplifies the received signal and forwards it to D by the transmit antenna $\tilde{l}$ at the second time slot. The received signal at the destination D with AF protocol can be written as,

$$y_{AF}^{RD} = G h_{\tilde{l}}^{RD} y^{SR} + n^{RD} , \quad (10)$$

where $h_{\tilde{l}}^{RD}$ denotes the maximal channel coefficient $h_{\max}^{RD}$ of $\mathbf{h}^{RD}$. $G = \sqrt{\frac{P_R}{P_S \left|h_l^{SR}\right|^2 + N_0}}$ is the amplification factor and n^{RD} is the AWGN with variance N_0. With simple manipulations, (10) can be rewritten as,

$$y_{AF}^{RD} = G h_{\tilde{l}}^{RD} h_l^{SR} x_q + \tilde{n}^{RD} , \quad (11)$$

where $\tilde{n}^{RD}$ is the AWGN noise with variance $G^2 \left|h_{\tilde{l}}^{RD}\right|^2 N_0 + N_0$.

Finally, the destination node D will combine the signals form S and R together with ML detection and make the final decision. The signal at the destination D can be expressed as,

$$y = y^{SD} + y_{AF}^{RD} \quad (12)$$

or

$$y = y^{SD} + y_{DF}^{RD} . \quad (13)$$

Destination D deals with the received signal y with ML detector, which mainly calculates the Euclidean distance between the received signal and the possible input signals and decides the index of the activated antenna, the ML detection can be computed as,

$$[\hat{l}, \hat{x}_q] = \arg\min_{l, x_q} \left\| y - h_l x_q \right\|^2 , \quad (14)$$

where $h_l \in \{h_{l,\mathrm{AF}}, h_{l,\mathrm{DF}}\}$. $h_{l,\mathrm{AF}}$ and $h_{l,\mathrm{DF}}$ denote the effective channel coefficients when the relay employs AF relaying protocol or DF relaying protocol, respectively, which can be calculated respectively as $h_{l,AF} = h_l^{SD} + G h_l^{SR} h_{\max}^{RD}$ and $h_{l,DF} = h_l^{SD} + h_l^{RD}$.

III. Simulation Results and Analysis

In this section, we present the simulation results about the outage probability performance of the IHDAF protocol based cooperative SM system. The system simulation parameters are listed in Table 1.

TABLE 1. Simulation Parameters

Parameter	Value
Transmit antennas of S and R	4
Receive antennas of S and R	1
Pass loss factor α	3.0
Pre-determined rate R	3bits/s/Hz
Threshold SNR_{SD}	1
Threshold SNR_{SR}	3
Power allocation factor δ	0~1
Normalized distance between S and D d_{SD}	1
Normalized distance between S and R d_{SR}	0~1
Normalized distance between R and D d_{RD}	1-d_{SR}

Figure 3 depicts the outage probability of the IHDAF relaying based SM system with equal power allocation scheme (δ=0.5) and the distance between S and R is fixed to be 0.5. We also compare the IHDAF relaying based SM system with AF and DF relaying based SM systems. The simulation results show that the outage probability of the proposed IHDAF based cooperative SM scheme achieves the best performance compared with AF and DF based cooperative SM schemes. When the outage probability is 10^{-3}, the IHDAF based cooperative SM scheme obtains about 3.0dB and more than 8.0dB gains compared with AF and DF based cooperative SM schemes, respectively. It is shown that the IHDAF relaying based cooperative SM can improve the system performance significantly. At high SNR region, the superiority of the IHDAF protocol based cooperative SM system becomes more obvious compared with DF relaying based cooperative SM system.

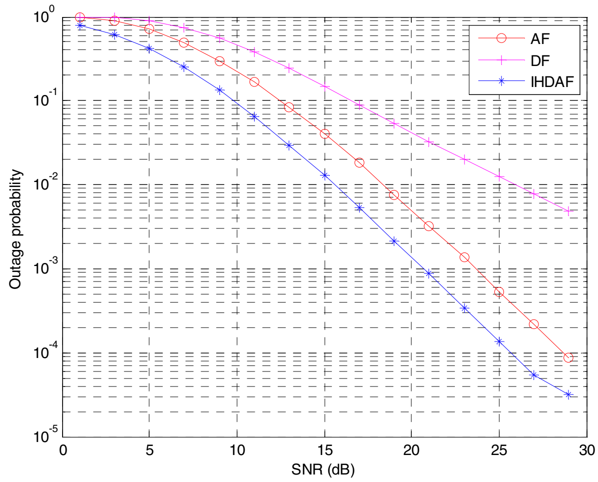

Figure 3. Outage probabilities of the IHDAF, AF and DF based cooperative SM systems with d_{SR}=0.5, δ=0.5.

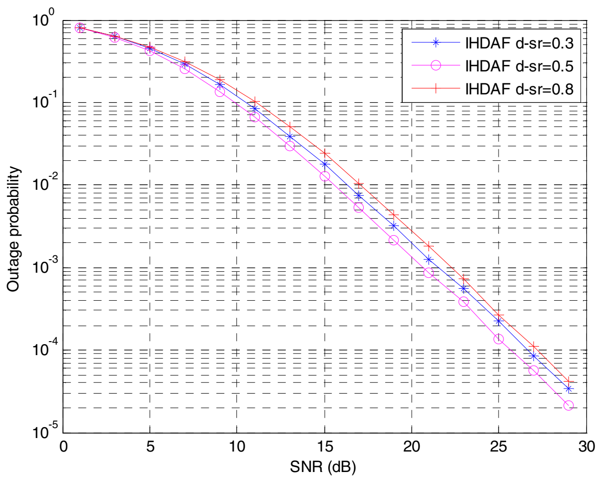

Figure 4. Outage probability comparison of IHDAF based cooperative SM between different d_{SR} with δ=0.5.

Figure 4 and Figure 5 present the outage probabilities of the IHDAF scheme based cooperative SM system with equal power allocation scheme considering different distances between *S* and *R*. As shown in Figure 4, the performance of the IHDAF relaying based cooperative SM scheme with d_{SR} = 0.5 obtains the best outage performance. When the outage probability is 10^{-3}, the IHDAF based SM scheme with d_{SR} =0.5 obtains about 0.9dB and 1.4dB gains compared with the case d_{SR} =0.3 and d_{SR} =0.8, respectively. We can also draw the conclusion from Figure 5 that the outage probability of IHDAF based cooperative SM system will go down first and then go up with the increase of d_{SR}, and the optimal outage performance will be obtained at d_{SR}=0.5, which means the relay node locates in the middle of the source and destination nodes.

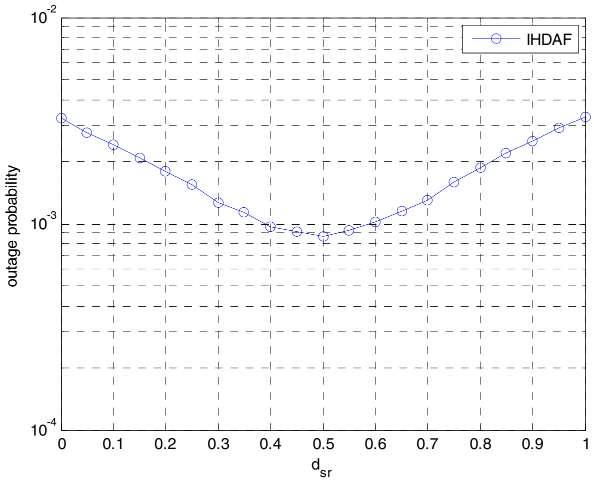

Figure 5. Outage probability comparison of IHDAF cooperative SM between different d_{SR} with δ=0.5, SNR=20.

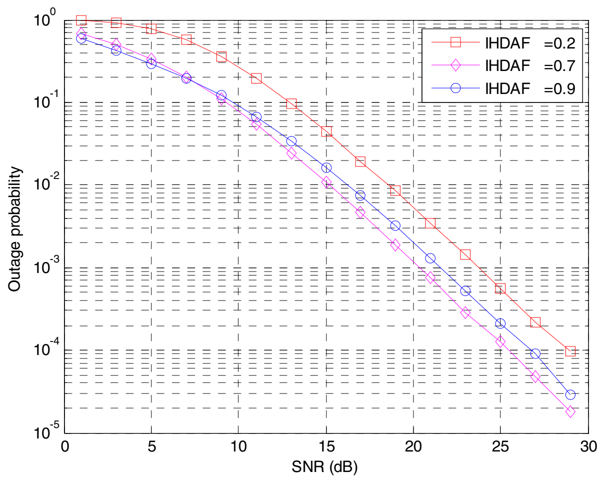

Figure 6. Outage probability comparison between IHDAF cooperative SM between different δ with d_{SR}=0.5.

The outage probabilities of the IHDAF based cooperative SM system with different power allocation factors are shown in Figure 6 and Figure 7. As shown in Figure 6, it is seen that the proposed IHDAF based cooperative SM scheme with δ=0.7 outperforms the schemes with δ=0.2 and δ=0.9. For example, when the outage probability is 10^{-3}, the scheme with δ=0.7 achieves about 3.8dB and 1.4dB gains compared with the schemes with δ=0.2 and δ=0.9, respectively. Figure 7 also shows the outage performance trend with different power allocation factor δ, which shows that the power allocation factor is an important factor affecting the system. When the power allocation factor δ is 0.7, the system outage probability achieves the best performance.

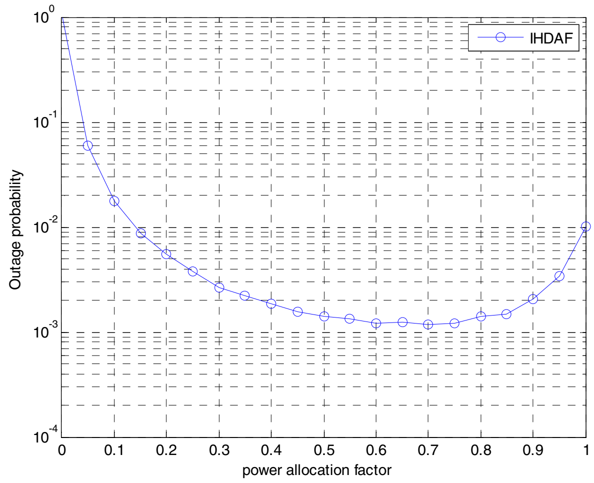

Figure 7. Outage probability comparison of IHDAF cooperative SM between different δ with d_{SR}=0.5, SNR=20

IV. Conclusions

In this paper, an incremental hybrid decode-amplify-forward protocol based cooperative spatial modulation is proposed to improve the system performance and utilize the characteristics of channel conditions and SM. The system model of the proposed scheme and the corresponding signal processing algorithm are presented in detail. The system performance of the outage probability considering the different locations of the relay node and the different power allocation schemes is provided in the simulation. The simulation results show that the IHDAF relaying based cooperative SM achieves significant performance improvement compared with the conventional AF and DF based cooperative SM schemes. Furthermore, the best relay location and power allocation factor are obtained in this paper.

Acknowledgment

This work is supported in part by International Science & Technology Cooperation Program of China (No. 2015DFG12580), National Science foundation of China (No. 61301147 and 61471180), the Fundamental Research Funds of Shandong University (No. 2016JC010), and National Research Foundation of Korea (2014K1A3A1A20034987).

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