협력 통신에서 시공간부호의 최대 사용 효율

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A Full Utilization of Space-time Block Code in Cooperative Communications

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요 약

본 논문에서는 신호를 소스에서 목적지로 전송하는 것을 도와주는 중계기에 Hurwitz-Radon space-time 부호를 사용한 협력통신을 제안한다. 전송안테나가 2개인 시스템이 간단하고 고속의 데이터 율을 제공하기 때문에 보다 자세히 설명한다. 해석과 시뮬레이션은 제안한 시스템이 최대 다이버시티 계수 3을 획득하는 것을 증명한다. 또한, ML 수신기를 수식적으로 유도하고 결합 기법이 아주 간단한 것을 볼 수 있다.

Key Words : Cooperative Communication, STBC, Dversity, ML Receiver AF

ABSTRACT

We propose a cooperative transmission scheme that uses Hurwitz-Radon space-time code for the relays which help the source to transmit signals to the destination, the full utilization here is that the destination utilizes the broadcast symbols from the source. We present the 2 transmit antennas case in detail because of its simplicity and high data rate. Analysis and simulations show that the proposed scheme achieves full diversity order of 3. The maximum likelihood receiver is also derived and the combining scheme is shown to be very simple.

Ⅰ. Introduction

Multipath fading causes severe impairments to wireless communications[1]. The fluctuation in signal due to fading can be compensated by power control at the transmitter, but this approach results in high complexity and large power consumption. Another reasonable approach is to use independent versions of signals (hence the name diversity) whose combination is less fluctuating. Transmit diversity recently has been intensively studied since Alamouti first introduced the simple transmit diversity scheme for two transmit antennas[2]-[4]. But using multiple antennas raises problems such as: size, cost, etc. which are not appropriate for mobile phone networks or wireless sensor networks, etc. Consequently, the idea of forming a virtual multiple antenna array from single antenna-devices has been introduced and resulting in a huge research field called cooperative communication.

Applications of Hurwitz-Radon space-time code for the wireless relays were presented by Y. Hua et al., [5] each relay is assigned one Hurwitz-Radon code and forwards the modified sequences of the

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noisy received signals in parallel to the destination. They showed that with large number R of relays, a diversity order around R/2 can be achieved and the special case of R=2, the diversity order is about 1.6. However, the most important and most reliable information from the source has been ignored, and only noisy versions of the signal are transmitted to the destination, later on we will show that the quality of the transmission depends heavily on the information that the destination receives directly from the source. Similarly, the Alamouti-based multihop transmission proposed by X. Li [9] also discards the most reliable information. Only Anghel et al. proposed applying the Alamouti scheme for the two relay transmission and utilized the information from source [8], but they did not show how important that information is.

In this paper, we propose using Hurwitz-Radon space-time code for the relays and also let the destination keep the original signal it receives from the source, after linear processing we combine the decoupled signals from the relays and the signals from the source. The case of 2 transmit relays is presented in detail due to the fact that it is the unique code existing for complex constellation with full rate. Moreover, complexity increases when the number of relays increases, the simplicity of 2 transmit relays make it specially attractive for practical applications.

The remains of the paper is organized as follows. In section II we present system model, and details of transmission process. We also derive an maximum likelihood detector for the proposed scheme in section III. Simulation results are given in section IV together with comments. Finally, we conclude the paper in section V.

Ⅱ. System model

In Fig. 1, we consider a cooperative communication system that includes: 1 Source (S), 2 relays (R_1 ,R_2) and 1 destination (D) all of which communicate in wireless environment, 2 relays help the source to transmit signals to the destination. To prevent interferences, each node is assigned a different orthogonal channel. The channel effect between node i and node j (i, j =S, D, R_1, R_2) may be modeled by a multiplicative distortion h_{ij} which is an i.i.d complex Gaussian random variable with variance $\frac{\lambda_{ij}}{2}$ per complex dimension. The wireless channel is assumed to be quasi-static so that the path gains are constant over a frame of 2 symbols and change independently from one frame to another. The quasi-static condition for the two-symbol period is easy to satisfy because the individual channel is required to be unchanged for a short period. If we use more than two relays, the channel needs to be unchanged for the period of 4 symbols or more, this condition is more frequently unsatisfied, hence resulting in destruction of orthogonal structure of Hurwitz-Radon space-time code. The discrete-time equivalent complex base-band model is used for simple exposition. All the noise samples are modeled as i.i.d zero-mean complex Gaussian random variables with variance 0.5 per complex dimension.

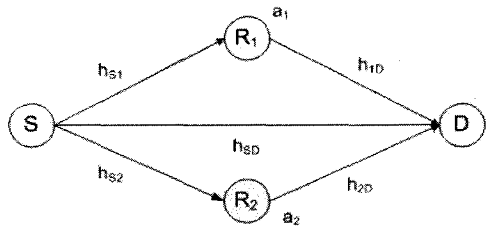

그림 1. 협력 전송 모델
Fig. 1 The cooperative transmission model

The cooperative protocol includes two phases, in the first phase, the source broadcast two MPSK symbols x_1, x_2, the destination and the relays receive the following signals:

$$y_{Si,l} = a_0 h_{Si} x_l + n_{Si,l} \tag{1}$$

where

- $y_{Si,l}$ is the received signal at node i (i = D, R_1, R_2) in the l-th symbol period, l=1,2.
- $n_{Si,l}$ is the noise sample at node i in the l-th symbol period.
- $a_0 = \sqrt{P_S}$ is an amplification factor at the source and P_S is the transmit power of the source.

Table. 1 Arrangement of signals at the relays

R1	$a_1 \frac{h_{S1}^*}{\lvert h_{S1}\rvert} y_{S1,1}$	$-a_1 \frac{h_{S1}}{\lvert h_{S1}\rvert} y_{S1,2}^*$
R2	$a_2 \frac{h_{S2}^*}{\lvert h_{S2}\rvert} y_{S2,2}$	$a_2 \frac{h_{S2}}{\lvert h_{S2}\rvert} y_{S2,2}^*$

In the second phase, the relays rearrange the received signal as Table. 1 and transmit, the received signal at the destination is:

$$\begin{aligned} r_1 &= h_{1D} a_1 \frac{h_{S1}^*}{|h_{S1}|} y_{S1,1} + h_{2D} a_2 \frac{h_{S2}^*}{|h_{S2}|} y_{S2,2} + n_{D,1} \\ &= a_1 a_0 |h_{S1}| h_{1D} x_1 + a_1 a_0 |h_{S2}| h_{2D} x_2 + a_1 h_{1D} n'_{S1,1} \\ &\quad + a_2 h_{2D} n'_{S2,2} + n_{D,1} \end{aligned} \tag{2}$$

$$\begin{aligned} r_2 &= -h_{1D} a_1 \frac{h_{S1}}{|h_{S1}|} y_{S1,2}^* + h_{2D} a_2 \frac{h_{S2}}{|h_{S2}|} y_{S2,1}^* + n_{D,2} \\ &= -a_1 a_0 |h_{S1}| h_{1D} x_2^* + a_1 a_0 |h_{S2}| h_{2D} x_1^* - a_1 h_{1D} n'_{S1,2} \\ &\quad + a_2 h_{2D} n'_{S2,1} + n_{D,2} \end{aligned} \tag{3}$$

where

- r_l is the received signal at the destination in the l-th symbol period, l =1, 2.
- The terms $\frac{h_{Si}^*}{|h_{Si}|}$, $\frac{h_{Si}}{|h_{Si}|}$ are to correct the phase distortion by the channel between the source and the relays, i =1, 2.
- The noise terms $n'_{Si,j}$ is the phase-shifted version of $n_{Si,j}$, $n_{D,i}$ is the noise sample at the destination in the i-th symbol period.
- a_i is the amplification factor at the node i. To maintain an average power[6] at the relay i, a_i is chosen as

$$a_i = \sqrt{\frac{P_i}{E(|y_{Si,l}|^2)}} = \sqrt{\frac{P_i}{P_S \lambda_S + 1}} \tag{4}$$

P_i is the transmit power of relay i.
Let

$$h_1 = a_0 a_1 |h_{S1}| h_{1D} \tag{5}$$

$$h_2 = a_0 a_2 |h_{S2}| h_{2D} \tag{6}$$

$$n_1 = a_1 h_{1D} n'_{S1,1} + a_2 h_{2D} n'_{S2,2} + n_{D,1} \tag{7}$$

$$n_2 = -a_1 h_{1D} n'_{S1,2} + a_2 h_{2D} n'_{S2,1} + n_{D,2} \tag{8}$$

We rewrite (2), (3) in a more compact form

$$r_1 = h_1 x_1 + h_2 x_2 + n_1 \tag{9}$$

$$r_2 = -h_1 x_2^* + h_2 x_1^* + n_2 \tag{10}$$

At this point, the destination has a collection of the stored signals from the first phase and the two new overlapping receive signals from the second phase. Because this scheme is different from the multiple receive antenna scheme, so we can not apply the MRC technique. Our next task is to find out how to detect the signal optimally, assuming that the transmit symbols have equal prior probability.

Ⅲ. Design of Maximum likelihood (ML) receiver

The symbol x_1 and x_2 play a similar role, so we will derive the estimated symbol of x_1, the estimated symbol of x_2 can be achieved straightforwardly in a similar way.

We wish to design a signal detector that makes a decision on the transmitted signal x_1 based on the observation of $y_{SD,l}$, r_1, r_2 such that the probability of a correct decision is maximized. With this goal in mind, we consider a decision rule based on the computation of the posterior probabilities defined as

$$\begin{aligned} &P(x_1 = s_m | y_{SD,1}, r_1, r_2) \\ &= \frac{p(y_{SD,1}, r_1, r_2 | x_1 = s_m) P(x_1 = s_m)}{p(y_{SD,1}, r_1, r)} \end{aligned} \tag{11}$$

where s_m, m=1,2,⋯,M, are MPSK symbols. P stands for Cumulative Distribution Function and p denotes Probability Density Function. The maximum a posteriori probability criterion is to select the symbol corresponding to the maximum of the set of posteriori probabilities. However, with the assumption that all the transmitted symbols have equal priori probability and notice that $p(y_{SD,1}, r_1, r_2)$ is the same for any transmitted symbol, the criterion becomes choosing s_m, if it maximizes $p(y_{SD,1}, r_1, r | x_1 = s_m)$.

Because the channel estimation is assumed to be perfect, the noise terms $n_{SD,1}, n_1$ and n_2 are independent Gaussian random variables with variance, $\sigma^2_{n_{SD1}} = 1, \sigma^2_{n_1} = \sigma^2_{n_2} = N = a_1^2 |h_{1D}|^2 + a_2^2 |h_{2D}|^2 + 1$.

The likelihood function is given by

$$p(y_{SD,1}, r_1, r_2 | x_1 = s_m) \quad (12)$$
$$= \frac{1}{\pi^{3/2} N} \exp\left(- \frac{\| y_{SD,1} - a_0 h_{SD} s_m \|^2}{1} \right)$$
$$\times \exp\left(- \frac{\| r_1 - h_1 x_1 - h_2 x_2 \|^2}{N} \right)$$
$$\times \exp\left(- \frac{\| r_2 + h_1 x_2^* - h_2 x_1^* \|^2}{N} \right)$$

Maximizing this function is equivalent with minimizing the following distance metric

$$D(s_m; y_{SD,1}, r_1, r_2) = \| y_{SD,1} - a_0 h_{SD} s_m \|^2 + \frac{\| r_1 - h_1 x_1 - h_2 x_2 \|^2 + \| r_2 + h_1 x_2^* - h_2 x_1^* \|^2}{N} \quad (13)$$

After expanding the metric, we ignore all the terms that are common to the all the symbol s_m or not relevant to the detection of x_1, the result is the distance metric of the possible transmitted signal and the estimated symbol

$$D(s_m, \hat{x}_1) = \| s_m - \hat{x}_1 \|^2 \quad (14)$$

where the estimated symbol of x_1

$$\hat{x}_1 = a_0 h_{SD}^* y_{SD,1} + \frac{r_1 h_1^* + r_2^* h_2}{N} \quad (15)$$
$$= \left(a_0^2 |h_{SD}|^2 + \frac{|h_1|^2 + |h_2|^2}{N} \right) x_1$$
$$+ a_0 h_{SD}^* n_{SD,1} + \frac{n_1 h_1^* + n_2^* h_2}{N}$$

Using a same approach, we can derive the estimated symbol of x_2

$$\hat{x}_2 = a_0 h_{SD}^* y_{SD,2} + \frac{r_1 h_2^* - r_2^* h_1}{N} \quad (16)$$
$$= \left(a_0^2 |h_{SD}|^2 + \frac{|h_1|^2 + |h_2|^2}{N} \right) x_2$$
$$+ a_0 h_{SD}^* n_{SD,2} + \frac{n_1 h_2^* + n_2^* h_1}{N}$$

These results show that the combining scheme is different from the MRC, however it remains as simple as MRC which is used in multiple antenna system. In MRC, each link is weighted by the conjugate of the channel gain and scaled by the noise variance. In our ML receiver, the direct link from the source to the destination is weighted in the same way of MRC, the two signals received from relay links, similar to MRC in noise scaling, are either conjugated or not and weighted by channel gain or its conjugate according to the Alamouti scheme. We can see the estimated symbols after decoupling and combining are from 3 independent links, so the diversity order of 3 is guaranteed.

Ⅳ. Simulation results

In this section, we use Monte-Carlo simulations to verify our protocol. In all the following figures, the signal-to-noise ratio is defined as SNR=P_T, where P_T is the average power of direct transmission (DT) from source to destination without assistance of any relay. It is assumed that the total transmit power of the source and the relays is the same as the transmit power of the direct transmission $P_S+P_1+P_2=P_T$. In Figure 2, we consider the symmetric network, i.e., $\lambda_{SD} = \lambda_{SR_1} = \lambda_{SR_2} = \lambda_{R_1D} = \lambda_{R_2D} = 1$. The result confirms the importance of the signals that the destination receives directly from the source, here, P_S=0.6 means that $P_S=0.6P_T$ and $P_1=P_2=0.4P_T/2$. Obviously, the more power assigned for the source, the better the performance, and inversely, when we increase the power for the relays and reduce power for the source, the performance decreases. The reason is that the directly received signal is more reliable than the signal re-

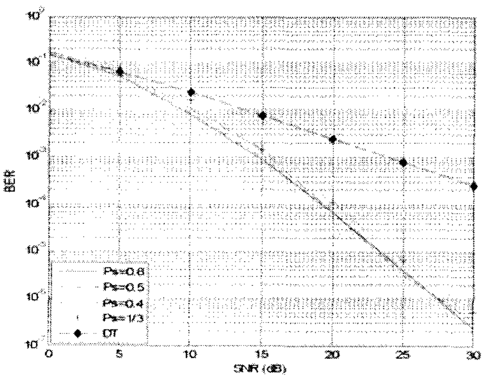

그림 2. 전력 할당에 따른 BER 성능
Fig. 2 BER Performance comparison of different power allocation strategies

ceived from intermediate nodes. As a matter of fact, the noisy information of the two relays is from the source in the first phase, the more power allocated for the source in the first phase, the less noisy the relay information is. In addition, if we increase the relay power, it also amplifies the noise. Consequently, the information of the source is the most important and should be allocated significant amount of power, cooperation power of the relays should be kept at low level. This allocation strategy is highly desired in wireless networks because relay nodes or users just want to spend small amount of power to help other nodes, the burden of power consumption still belongs to the node that needs to communicate. Moreover, the slopes of the BER curves increase with increasing SNR, in the 25 dB - 30 dB SNR range, the measured diversity order is about 2.8, and at the higher SNR range, the diversity order is shown in the previous section to be 3.

The effects of source-destination (SD) channel variations is considered in Figure 3, all other channel conditions remain unchanged, i.e., $\lambda_{SR_1}=\lambda_{SR_2}=\lambda_{R_1D}=\lambda_{R_2D}=1$. Both the direct transmission and cooperation have a variation in the channel condition between the source and the destination, i.e., $\lambda_{SD}=0.5, 1, 2$. The performance of the proposed protocol is less affected than the direct transmission, the differences between performances of the proposed are about 1 dB compared with 3 dB of the direct transmission. So, in the cooperation case, it is easy to provide a widerange of QoS (Quality of Service), we only need to change slightly the power to achieve the desired QoS. We also notice that the diversity order is not affected by the channel conditions.

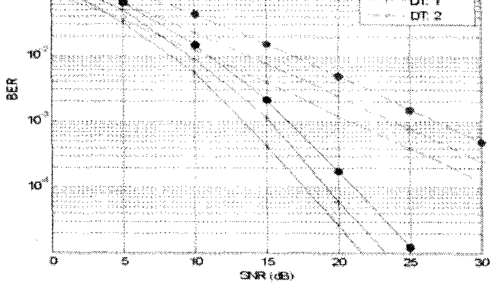

그림 3. 소스-목적지 사이의 채널 변화에 따른 제안한 프로토콜의 BER 성능

Fig. 3 BER performance of proposed protocol under variation of the source-destination channel

V. Conclusion

We presented a full utilization of space-time block code in cooperative communication. The utilization is based on an important notice that the original information broadcast from the source contributes significant improvement to the performance. Moreover, exploiting that information also increases 1 diversity order. The design fundamental always requires that the transmission protocol should be kept at the lowest complexity, and the 2-relay case is a promising protocol that satisfies this condition. It has been shown that the Alamouti scheme is successful in the MIMO applications, in a similar way, we believe that the 2-relay case will be first successful if cooperative communication comes into realization.

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