Novel Relay Cooperative Transmission Schemes Based on OFDM System

Yongtai Xu

China Academy of Telecommunication Research of MIIT, Beijing, 100191, China

email: xuyongtai@catr.cn

Keywords: Cooperative System; Diversity; OFDM; Relay

Abstract. In this paper, a transmission protocol is firstly introduced based on the OFDM cellular cooperation system. Considering the constraints of the size of mobile terminal, we propose two main cooperative schemes to obtain transmitting diversity which is difficult for common transmission methods to acquire. In our structure, at the same time the destination could cooperatively process the signals from two independent paths, one is direct and the other is via a relay. Both of our two schemes are based on a not-fully-regenerative manner. One of our schemes could be used to achieve uplink transmission diversity, and the other one could be utilized in both uplink and downlink transmission. To enhance the performance of the second scheme in different situation, we recommend three supplementary strategies which could alter adaptively according to the condition. The complexity in our schemes is low, and from the simulation results, we could observe that our cooperative approaches could achieve transmitting diversity and obtain good performance.

Introduction

It has been widely accepted that transmitters that have more than one antenna could use space time code process to increase throughput and improve end to end system performance. However, it is hardly to adopt these advanced technologies due to the size and cost limitations of mobile terminals. On the other hand, it has long been known that transmitting signals through independent paths could improve the performance of wireless communication system in the fading channel. So a new approach of diversity, cooperative diversity, has been proposed and discussed in several studies, such as [1-3]. In a cooperative transmission system, when one user is transmitting information to a remote terminal and the direct path is not reliable, other nearby terminals or relays could receive the signal from the source and forward it to the destination.

Previous scholarly work includes both capacity analysis of cooperative system and introduction of practical cooperative codes design. It is shown in [1-2] that a substantial increase of the rate region is achievable in a two-user cooperative system in the flat fading channel from information-theoretic aspect. Several simple algorithms for cooperative transmission are developed in [4], such as amplify-and-forward mode and decoded-and-forward mode. Two extensions to the coded cooperation framework are introduced in [5], which provides space-time codes and turbo codes cooperation. Analysis in [6] includes the iterative decoding at the relay. Performance analysis of channel coding cooperation and a code design criteria are provided in [7]. The strategies proposed in these studies could acquire cooperative diversity, but the implement complexity brought in is at a high level, especially in relay node operation such as iterative decoding. There is simple AF mode in one relay system, but the performance improvement is limited. We wish to find a simple but effective method that would achieve the cooperative diversity without bringing in much implement difficulties.

In this paper, based on the structure with one source, one relay and one destination, we propose two cooperative schemes that could effectively acquire transmitting diversity in the system that the mobile terminal only has one antenna. And in order to simplify the function of relay, we avoid adding much complex work to relay in our schemes. Either mobile terminal or signal processing station could take its role in our system. The destination in our schemes would receive and process the signals from the relay and source at the same time. Many our signal processing methods, including interference cancellation and the MMSE detection manner, would be laid at the destination. When our system serves the downlink transmission, these strategies could be simplified. Based on the OFDM system, our signal process methods could vary according to the condition of sub-carriers. Our scheme 1 is mainly used in uplink transmission, and scheme 2 could serve both uplink and downlink transmission. We would take easiness of system implementation into consideration.

The paper is organized as follows. In Section II, we describe a source-relay-destination system model and introduce a cooperative transmission protocol. Section III proposes two cooperative schemes based on our model to obtain cooperative diversity. Section IV evaluates these schemes and presents the performance of our strategies. Our conclusion is in Section V.

System Model

In our cooperative system model, we adopt a basic cooperative structure that contains three main nodes, one source node, one relay node, and one destination node. And each channel in this model is an independent fading path. The structure is depicted in Fig.1. In the uplink transmission, the destination node could represent the base station that would have multiple antennas to gain better performance and the source node only need to employ one antenna. In the downlink transmission scenario, source represents the base station, and destination takes the role of the mobile terminal.

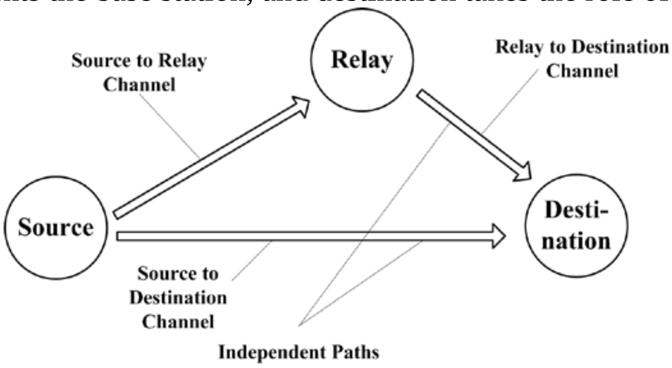

Fig.1. Cooperative System Structure

As is shown in Fig.1, source not only sends signals to destination, but also to relay. In order to acquire much higher level of throughput, the signals in the two channels had better be different. But we also suggest that two flows of signals should have relationship with each other, from which system would gain benefits. To balance the throughput and performance, we decide to send different check bits flows out of the channel encoder through different channels. Owning to the natural fit, turbo code could be used in our schemes. As for the modulation mode in the system, QPSK and 16QAM are taken into consideration. To counteract the impact of the fading channel and support high-speed data transmission, the cooperative system would be based on the OFDM principle. In order to obtain better performance, not all the sub-carriers are being used; some of them would be empty.

In the traditional cooperative system, there would be two main methods to process signal at the relay node, which are called AF mode and DF mode. But we suggest a manner different from them, which we call not-fully-regenerative manner. It means that we only need to regenerate the signals to the symbol level, not to fully decode them. Our signal operation and design would be based on the symbols. And at the relay node, FFT and IFFT process would be needed.

The transmission protocol used in our cooperative schemes is founded on the time slot. Each transmission frame attempts to use two time slots. The manner of information allocation and transmission is shown in Fig.2 (a1, b1, c1 represent three parts in one frame). In the first slot, source sends part of the signals to relay. And in the second time slot, relay would process the signals and transmit them. Simultaneously source would send the other part of original signals to destination. Based on the signals correlated property, we could make cooperative combination at the destination. This transmission protocol would not only maintain a certain level of throughput, but also achieve path diversity. The detailed cooperative schemes and analysis would be introduced in the next section.

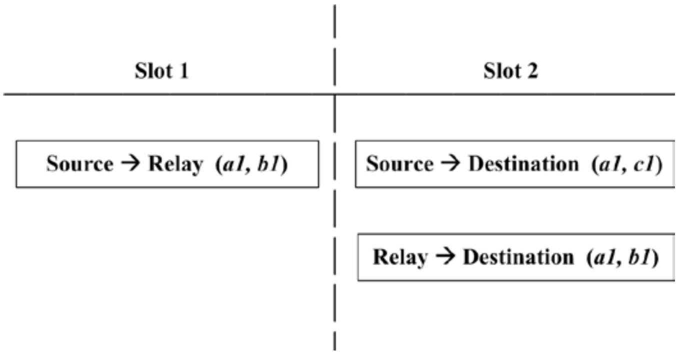

Fig.2. Transmission Protocol and Information Allocation

Cooperative Transmission Schemes

In our schemes, the source node needs to divide the information signals into two parts. One is sent to relay and the other is directly sent to destination. Our cooperative strategies mainly focus on the operation in the relay and destination.

Scheme I:

To improve the system reliability, forward error correction is based on turbo code and iterative decoding is suggested. We adopt 1/3 turbo code and denote a, b and c to represent three parts of bits sequence out of the turbo encoder (a representing the information bits, b and c representing the check bits). Our cooperative scheme suggests re-ordering and re-combining the source bits at the source node. To some extends, this strategy would compensate the performance loss caused by signals not fully decoded at the relay.

Suppose that the length of b and c is n1. Firstly, we randomly choose half number of bits from b, and then add the other half of n1 bits chosen from c to generate b' that would be sent to the relay node after combined with information bits a. And remaining bits are merged into second part bits c' that being sent through source to destination channel with a. The signal cooperation part in transmitter is shown in Fig.3.

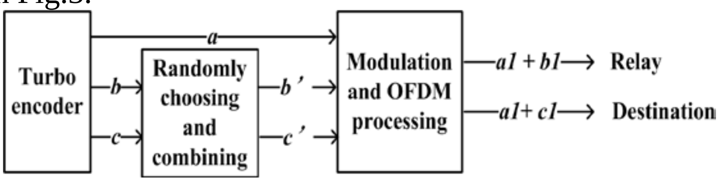

Fig.3. Source Node Signal Processing in Scheme 1

In our schemes, relay node would take an important role, and our not-fully-regenerative manner would take part in this place. In the simple AF relay mode, performance would be affected by noise diffusion. From (1), we could know that n1, noise interference in source to relay channel, is magnified by h2. In order to compensate this performance declination, not-fully-regenerative manner needs to reshape the symbols to its modulation constellation points when relay receiving them.

$$y_{relay\_path} = h_2 \bullet (h_1 \bullet s_1 + n_1) + n_2 = h_{relay} \bullet s_1 + h_2 \bullet n_1 + n_2 \quad (1)$$

Only one antenna is needed at the relay node in our schemes. The work that relay ought to do after FFT processing and signal reshaping in scheme 1 is simple, just the source to relay channel estimation. The channel state information would be needed in further receiving process at the destination. And then, relay could process the symbols based on the OFDM principle and transmit them to destination.

When scheme 1 is adopted, destination node should have more than one antenna. Before receiving and processing the signals, synchronization among three nodes (source, relay and destination) should be obtained perfectly. Due to our scheme 1 mainly focuses on the uplink transmission, this assumption is rational and easy to implement at the destination part.

In the first step at the receiver, we need to separate the signal frame received and use effective channel estimation algorithm to gain channel information of both paths. Because of relay existing, the channel information from the relay path would be separated into two parts, h1 (source to relay channel) and h2 (relay to destination channel). Using the characteristic in frequency domain, we could combine the information of these two channels easily, given in (2). (hrelay representing the channel information from source to destination via relay)

$$h_{relay} = h_2 \bullet h_1 \tag{2}$$

In the second step, channel information matrix H is needed to be acquired, as in (3) (h3 representing direct source to destination channel state information).

$$H = \left[h_{2(rx\_dest \times 1)} \bullet h_{1(1\times1)}, h_{3(rx\_dest\times1)} \right] \tag{3}$$

$$Y = H \bullet X + N \tag{4}$$

$$\hat{X} = H^{+} \bullet Y \tag{5}$$

Using methods in matrices theory, we could get the Pseudo inverse of the matrix H (H+ representing). We could use H+ to adopt interference cancellation strategy to gain the signals sent from two paths one by one, shown in (6-10), whose principle derives from the method in [8], but the difference existing. Owing to the strategy used in OFDM system, we could process the signals based on sub-carriers. The one that has the best condition could be handled first. Due to the existence of the pseudo inverse, to accomplish this algorithm, more than one antenna is needed in the destination. (ri, received signals after ith times interference cancellation; (H+)i, the ith row of H+; w_i^T, zero-forcing vector; $\hat{s}_i$, the estimation of transmitting signals)

$$(H^{+})_i = \min\{(H^{+})_1, (H^{+})_2\} \tag{6}$$

$$w_i^T = (H^{+})_i \tag{7}$$

$$y_i = w_i^T r_i \tag{8}$$

$$\hat{s}_i = Est(y_i) \tag{9}$$

$$r_{i+1} = r_i - \hat{s}_i H \tag{10}$$

In the third step, cooperative combining would be required. Because of the correlative characteristic of signals from two paths, there would be performance improvement when using maximum likelihood decoding manner to deal with the first part of the received signals (a1), shown in (11).

$$\hat{a}_1 = \arg\min_{\hat{a}_1 \in S}\{d^2(a_{1source}, \hat{a}_1), d^2(a_{1relay}, \hat{a}_1)\} \tag{11}$$

The signal processing flowchart at the destination in scheme 1 is shown in Fig.4.

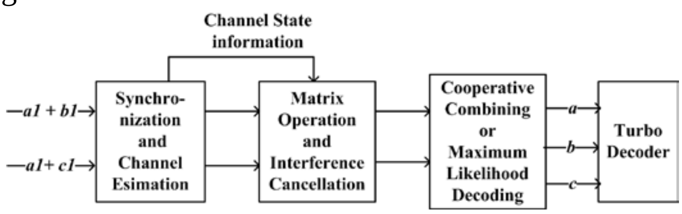

Fig.4. Destination Node Signal Processing in Scheme 1

Scheme 1 is a simple way to obtain transmitting diversity, and it would not bring much complexity to the source and the relay. Due to the requirement of multiple antennas at the destination, the application scope of scheme 1 would be uplink transmission in the cellular cooperative system.

Scheme II:

Scheme 2 that we recommend could serve not only uplink transmission, but also downlink transmission. In this scheme, we continue to use the signal transmitting mode in scheme 1, including turbo encoding, randomly choosing, OFDM modulating and cooperative combining, as shown in Fig.3.

At the relay node, we introduce the modification different from scheme 1. After FFT and reshape module, we propose to separate the first received signals sequence a1 that is shown in Fig.5 ($a_1 \rightarrow x_1, x_2$) and get the conjugation value of these symbols. From perspective of destination, the cooperative design could provide orthogonal transmitting diversity to the system, as suggested in (12-14). There are differences between our signal design and the one in [9]. In the viewpoint of implementation, we suggest that x_1 and x_2 have the same length.

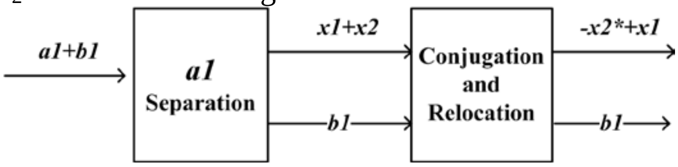

Fig.5. Relay Node Signal Processing in Scheme 2.

$$s_{source} = [x_1, x_2] \tag{12}$$

$$s_{relay} = [-x_2^*, x_1^*] \tag{13}$$

$$s_{source} \bullet s_{relay} = -x_1 \bullet x_2 + x_1 \bullet x_2 = 0 \tag{14}$$

In this scheme, we recommend three adaptive strategies at the destination to improve the performance of system in different situation. Perfect synchronization among three nodes and precise channel estimation are still required.

Based on the correlative characteristic in the frequency and time domain of received signals, we suggest using Minimum Mean Square Error (MMSE) algorithm in every receiver antenna to detect the signal in the first part (x1, x2), given in (15-17). (r_1^j, r_2^j representing received signals at the jth antenna in time slot 1 and slot 2; $h_{source}^{j,i}, h_{relay}^{j,i}$ respectively representing the channel state information at jth antenna in time slot i in the direct source to destination channel and the one via relay.)

$$r_1^j = h_{source}^{j,1} \bullet x1 - h_{relay}^{j,1} \bullet x2^* \tag{15}$$

$$r_2^j = h_{source}^{j,2} \bullet x2 + h_{relay}^{j,2} \bullet x1^* \tag{16}$$

$$(\hat{x}_1^j, \hat{x}_2^j) = \arg\min_{\hat{a}_1 \in S}\{d^2(r_1^j, h_{source}^{j,1} \bullet \hat{x}_1^j - h_{relay}^{j,1} \bullet \hat{x}_2^{j*}) + d^2(r_2^j, h_{source}^{j,2} \bullet \hat{x}_2^j + h_{relay}^{j,2} \bullet \hat{x}_1^{j*})\} \tag{17}$$

Maximum Ratio Combination (MRC) could be used to process the first sequence of signals (x1, x2) obtained after MMSE algorithm and diversity in multiple antennas could be acquired, shown in (18). The method in scheme 1 could also be used to process the second sequence of received signals (b1, c1). This mode could be used in the uplink transmission in the cellular system. The operation needed at the destination node in scheme 2 is depicted in Fig.6. As same as scheme 1, this method would not bring in much complexity to the relay and destination.

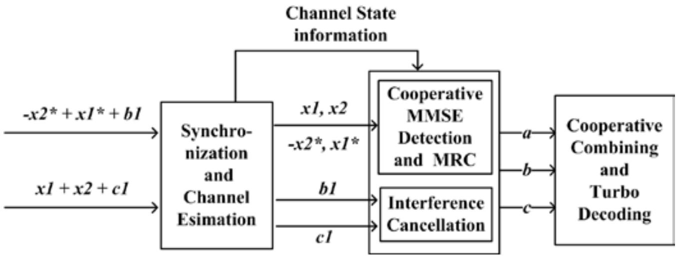

Fig.6. Destination Node Signal Processing in Scheme 2

$$\hat{x}_1 = \frac{\sum_{j}^{rx\_dest} \left(h^{j*} \bullet \hat{x}_1^j\right)}{\sum_{j}^{rx\_dest} \left|h^j\right|^2}, \quad \hat{x}_2 = \frac{\sum_{j}^{rx\_dest} \left(h^{j*} \bullet \hat{x}_2^j\right)}{\sum_{j}^{rx\_dest} \left|h^j\right|^2} \tag{18}$$

We propose an adaptive strategy for scheme 2 to serve the downlink transmission, which is because the method used in scheme 2 is based on the transmitting diversity and there is not restriction of number of antennas used in the destination. Under this circumstance, destination node could represent a mobile terminal with single antenna. We still use MMSE algorithm to process the first sequence (x1, x2), but due to single antenna at the destination, MRC module is not needed, so the complexity that we introduce to the destination could be lowered. In this strategy, when processing the second sequence part (b1, c1), the procedure of parallel to serial is needed. The interference cancellation module should be substituted by a parallel-to-serial and serial-processing one. Other modules would be same.

Based on the OFDM system, we propose a strategy of sub-carrier relocation adaptive to the variety of channel condition. In the wireless transmission, channel condition would have great impact to the system. As for the OFDM system, in specific wireless environment, the state of sub-carriers would be different. Based on the manner introduced in section II, not all the sub-carriers being used in our cooperative system, we could choose sub-carriers that have best condition to transmit signals in the relay. At this time, a feed back channel between destination node and relay node is needed in this strategy.

Similarly, cooperative system could involve retransmission manner using feed back channel between the relay and destination. We could use CRC code in the source part when processing original information. As is known to all, CRC code could provide code block check function and reflect whether the code blocks decoded right or not. If there are wrong bits in the code block, relay could get the information through the feed back channel, and retransmit the signal. Using this strategy, system would have better performance.

Due to adaptive manners, scheme 2 would serve both uplink transmission and downlink transmission in the cooperative cellular system. Relay node could reconstruct correlative and orthogonal characteristic of signals, which would achieve transmitting diversity effectively. Sub-carriers symbols relocation and retransmission strategy could also improve the performance of the system without bringing in much complexity.

Simulation Results and Analysis

The cooperative schemes are evaluated through simulation, which depends on the transmission protocol introduced in section II. In the simulation, we set system frequency at 2.5GHz, terminal speed at 10km/h. A 16-bit CRC code with generator polynomial G (16, 15, 2) and 1/3 turbo code in [10] are used. As for high speed transmission, 16QAM is utilized in the system. Furthermore, channels among three nodes accord with independent Rayleigh channel model. At the relay and destination node, channel state information is estimated perfectly, so is the synchronization. We use BER to examine the performance of the schemes.

Firstly, we compare our cooperative schemes to no relay system using maximum ratio combination strategy. The number of antennas at the destination is 4. The simulation result is shown in the Fig.7. When we simulate cooperative schemes, SNR in other two channels is set to 15dB. From the figure we could observe that at the same difficulty level of antennas implementation, our schemes could provide better performance than the system without relay, and our schemes have achieved uplink transmission diversity.

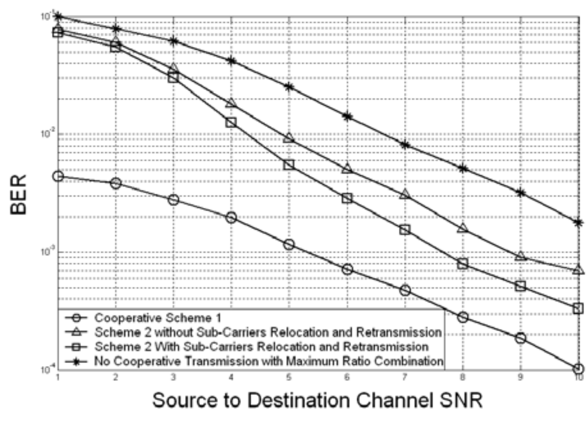

Fig.7. Comparing Our Schemes and No Relay Transmission Manner

From Fig.7 we could also observe that the sub-carrier relocation and retransmission strategy provides more than 1dB improvement contrasting to normal manner in scheme 2, when BER equals to 10-3, which proves that performance of our scheme 2 is enhanced with this adaptive strategy. In the simulation, relay signal retransmission time is set to 2 and ratio of useful sub-carriers in all carriers is 70%.

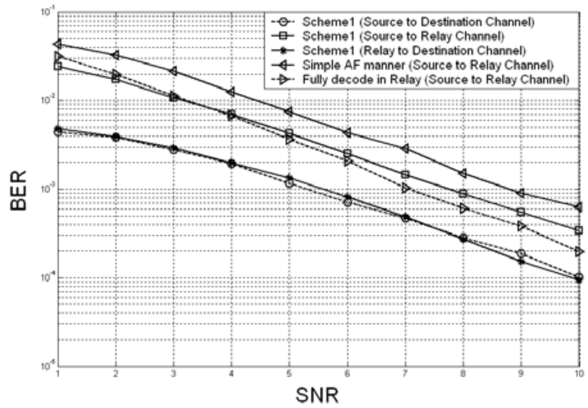

Fig.8. The Impact from the Variance of Channel Condition on the System

Additionally, we testify not-fully-regenerative manner used in our schemes and focus on the impact of different channels. From the perspective of source to relay channel, Fig.8 shows that our schemes have better performance than simple AF mode and the performance of our scheme and relay-fully-decoding manner is similar, but the complexity that we introduce in is limited. So our not-fully-regenerative manner could bring benefit to the cooperative system. In Fig.8, we also observe that the source to relay channel has much greater impact than other two paths, which results from noise diffusion, shown in (1). So if we wish to have good communication quality through cooperative system, we need to find a little interfered channel between source and relay.

At last, we investigate in the situation of single received antenna at the destination. Fig.9 shows that the performance of cooperative system with one antenna is better than no relay system with one antenna, which means that adaptive strategies would be effective when used in downlink transmission.

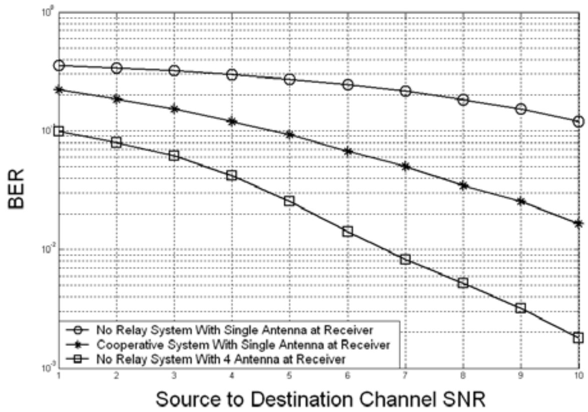

Fig.9. Comparing in the Situation of One Antenna at the Destination.

Conclusion

In this paper, a cooperative transmission protocol is described for transmission from a source node to a destination via one relay. And we propose two cooperative schemes to gain cooperative diversity in the cellular system. Scheme 1 mainly focuses on the uplink transmission. And scheme 2 could serve both uplink and downlink transmission. The difference of application scope of these two schemes results from the algorithm being used. Our schemes could solve the problem of the restriction that mobile terminals only have one antenna hardly to obtain transmitting diversity. From the perspective of implementation, there is no need to fully decode in the relay, so the complexity is limited. As shown in the simulation result, our cooperative schemes could achieve good performance. In order to enhance the performance of scheme 2 in different situation, we also provide three supplementary strategies including sub-carriers relocation and retransmission strategy.

In summary, our cooperative schemes based on the transmission protocol that we proposed could be a simple and effective way to obtain diversity and provide performance improvement to the communication system without bringing in much complexity.

References

[1] A. Sendonaris, E. Erkip, and B. Aazhang, “User Cooperation Diversity - Part I: System Description,” in Proc. of IEEE Int. Symp. on Info. Theory, Cambridge, MA, pp.156, Aug. 1998.

[2] A. Sendonaris, E. Erkip, and B. Aazhang, “User Cooperation Diversity - Part II: Implementation Aspects and Performance Analysis,” IEEE Trans. Commun., vol.51, pp.1939-1948, Nov. 2003.

[3] Wang Chaowei, Li Lihua, Xu Yongtai, Wang Haifeng, “A Novel Relay Cooperative Transmission Schemewith Bit Re-Ordering and Orthogonalization”, Journal of Beijing University of Posts and Telecommunications, Vol 33, No.1, Feb. 2010.

[4] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative Diversity in Wireless Networks: Efficient Protocol and Outage Behavior,” IEEE Trans. Inform. Theory, vol.50, no.12, pp.3062-3080, Dec. 2004.

[5] M. Janani, A. Hedayat, T. E. Hunter, A. Nosratinia, “Coded Cooperation in Wireless Communications: Space-Time Transmission and Iterative Decoding,” IEEE Trans. Signal Processing, vol.52, no. 2, pp.362-370, Feb. 2004.

[6] M. R. Souryal, B. R. Vojcic, “Cooperative Turbo Coding with Time-Varing Relay Fading Channels,” IEEE Communications Society, pp. 356-360, 2004.

[7] A. Stefanov, E. Erkip, “Cooperative Coding for Wireless Networks,” IEEE Trans. Commun, vol.52, no.9, pp.1470-1476, Sep. 2004.

[8] G. D. Golden, G. J. Foschini, R. A. Valenzuela and P. W. Wolniansky, “Detection Algorithm and Initial Laboratory Results Using the V-BLAST Space-Time Communication Architecture”, Electronics Letters, vol.35, no.1, pp.14-15, Jan. 1999.

[9] V. Tarokh, H. Jafarkhani and A. R. Calderbank, “Space-Time Block Codes from Orthogonal Designs”, IEEE Trans. Inform. Theory, vol.45, no.5, pp.1456-1467, Jul. 1999.

[10] C. Berrou, A. Glavieux, “Near Optimum Error Correcting Coding and Decoding: Turbo-codes,” IEEE Trans. Commun., vol.44, no.10, pp.1261-1271, Oct. 1996.