http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 8 (7): 1013-1019, 2009
ISSN 1812-5638

Performance Study of Cooperative Diversity System over Nakagami-m Fading Channels

Jingning Wang, Xuejun Sha, Linan Sun and Zhongzhao Zhang
Communication Research Center, Harbin Institute of Technology, Harbin, China

Abstract: In this study, a cooperative diversity scheme with decoded-and-forward plus amplify-and-forward is proposed by employing truncated stop-and-wait automatic repeat request for error control. All the transmission channels are assumed to exhibit Nakagami-m fading and the cross-layer performance is analyzed for the proposed scheme, such as the channel efficiency in physical layer, throughput and packet loss rate in link layer. The simulation results show that, the proposed scheme has the better cross-layer performance than other cooperative systems. By choosing a suitable partner, the proposed cooperative scheme can provide better performance than non-cooperative systems and spatial diversity gain can be obtained.

Key words: Cooperative diversity, automatic repeat request, decoded-and-forward, amplify-and-forward, cross-layer performance study

INTRODUCTION

Cooperative Diversity (CD) system is a promising candidate for emulating Multiple-Input-Multiple-Output (MIMO) system in which each mobile device only has a single antenna. The cooperation between two or more users in a wireless communication system can yield diversity gain (Sendonaris *et al*., 2003; Laneman *et al*., 2004). In a user cooperation system, when the sender (S) transmits signals to the destination (D), neighboring users can also receive the signals. And the neighboring users, called partners (P), can relay the signals to the destination. In this way, the antennas of the sender and the partners together form a multiple transmit antennas situation.

Performance analysis of CD systems yielded many interesting results including information theoretic metrics, outage probability and average error probability expressions over Rayleigh fading channels. In general, the CD systems reported in the literature are based on different techniques that maintain selecting the best partners for cooperation (Bletsas *et al*., 2006; Mahinthan *et al*., 2007a) and optimizing the power allocation (Zhou *et al*., 2008). Depending on the method used for forwarding at the partners, CD systems can be classified as amplify and forward (AF) or decoded and forward (DF) (Nosratinia and Hunter, 2007). In addition, the CD systems may employ fixed or adaptive relaying at the partner. In fixed relaying, the partner always forwards the received signals to the destination, regardless of whether they are erroneous (Mahinthan *et al*., 2007a). For adaptive relaying, it can be selection relaying or incremental relaying. Selection relaying forwards the information if the received signal strength is higher than a given threshold for error free reception or by checking the correctness of Cyclic Redundancy Checksum (CRC) of a frame of information bits.

In order to increase the performance of the CD systems, an automatic repeat request (ARQ) scheme is necessary at the link level and a Quadrature Signaling (QS) CD scheme with DF and ARQ is an effective method (Mahinthan *et al*., 2009). And cross-layer performance is studied, such as Packet Loss Rate (PLR), throughput and channel efficiency. However, the QS-DF-ARQ scheme is based on DF only and there is some channel resource loss when the partner can not decode the signals transmitted by the sender correctly. So, a CD-ARQ scheme based on DF plus AF (DF+AF) scheme is proposed and the cross-layer performance is analyzed in this study.

In this study, we consider a cooperative communication system based on DF pulsing AF: if the partner can not decode the signal correctly, the partner will amplify and forward the received signal to the destination. The cross-layer performance is studied over the Nakagami-m fading channels. And the cross-layer performances of the noncooperative scheme, QS-DF-ARQ scheme, proposed DF+AF scheme and distributed space-time block coding (STBC) scheme are compared.

SYSTEM DESCRIPTION

We consider a two-user CD system that each user has a single antenna in the physical layer, as shown in Fig. 1. In this study, we consider QS in which

Corresponding Author: Jingning Wang, Post Box 312, No. 92, West Da-Zhi Street, Harbin, Heilongjiang, 150001, China
Tel: +86-13633601428, +86-451-86416904-8221 Fax: +86-451-86416916

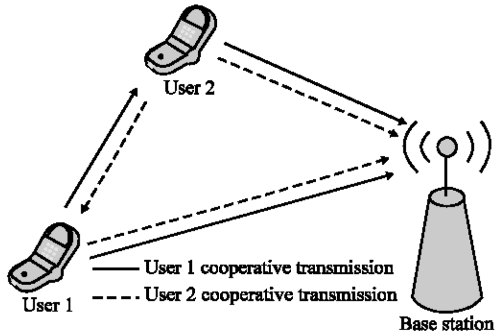

Fig. 1: Two-user cooperative diversity system

orthogonality can be achieved by expanding the signal constellation and transmitting in the in-phase and quadrature components of a quadrature amplitude modulation scheme. Details of the CD scheme and the advantage of QS can be found (Mahinthan *et al*., 2007b). Then, a cross-layer design is proposed by considering the QS-CD scheme at the physical layer with truncated stop-and-wait ARQ at the data link layer.

Channel model: Among the available distributions that describe the statistics of wireless fading channels, the Nakagami-m distribution is a generalized fading model. From this distribution, other distributions can be approximated by substituting the appropriate fading figure m. Therefore, we consider the channels between the sender and the partner {S,P}, the sender and the destination {S,D} and the partner and the destination {P,D} as exhibiting Nakagami-m fading and they are independent each other.

The probability density function (pdf) of the Nakagami-m distribution is given by:

$$p_R(r) = \frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m}\exp\left(\frac{-mr^2}{\Omega}\right) \tag{1}$$

where, r is the fading channel coefficient, is the fading figure, $\Omega = E[r^2]$ is the signal power and

$$\Gamma(m) = \int_0^\infty x^{m-1}e^{-x}dx$$

is the Gamma function. The joint pdf of r(t) and r(t+τ) can be obtained as:

$$\begin{aligned} f_{R_1,R_2}(r(t),r(t+\tau)) &= \frac{4m^{m+1}(r(t)r(t+\tau))^m}{\Gamma(m)\Omega^{m+1}(1-\rho)\rho^{m-1}} \\ &\times \exp\left(\frac{-m}{1-\rho}\left[\frac{r(t)^2+r(t+\tau)^2}{\Omega}\right]\right) \\ &\times I_{m-1}\left(\frac{2\sqrt{\rho}mr(t)r(t+\tau)}{\Omega(1-\rho)}\right) \end{aligned} \tag{2}$$

where ρ is the correlation coefficient and I_{m-1} denotes the (m-1)th-order modified Bessel function.

Cooperative transmission methods: For cooperative transmission, the sender broadcasts a frame of bits to the destination and the partner in orthogonal subchannel 1. The partner detects the signal from the sender and checks the correctness of the frame using CRC. If the received frame is correct, the partner forwards the decoded information in orthogonal subchannel 2, if the received frame is false, the partner amplifies and forwards the received signal in orthogonal subchannel 2. In contrast, in QS-DF-ARQ scheme (Mahinthan *et al*., 2009), the partner remains silent if the partner decoded the frame in error. And 1 bit information is included in the partner's information to the destination for marking the cooperative mode (AF or DF). At the destination, the signals from the sender and the partner are combined using Maximum Ratio Combining (MRC) to detect the frame. The correctness of the frame is checked using CRC. If the frame is correct, an acknowledgement (ACK) message is sent to the sender. Otherwise, a negative acknowledgement (NAK) message is sent to the sender. If the sender receives a NAK, it retransmits the frame if the number of retransmissions does not exceed the maximum retry limit L. In this mechanism, the partner does not need to be aware of the ARQ. This reduces the complexity of the partnering device. Details of the mechanism are described in Table 1, where P_1 and P_2 denote the power transmitted in noncooperative transmission by the sender and the partner, respectively. A graphical representation of the transmission mechanism is given in Fig. 2. To facilitate the performance study at high levels, independent of the underlying channel coding and modulation schemes, the frame error is decided upon by a signal-to-noise ratio (SNR) threshold SNR_T. SNR_T is the minimum received SNR that is required for correctly receiving a frame. Thus, if the received SNR is lower than the threshold, the received frame is considered erroneous and AF scheme will be started.

PERFORMANCE ANALYSIS

Here, the performance of the proposed DF+AF scheme is analyzed at the frame level, considering the physical-layer parameters and packet level, where a pocket from the upper layer is divided into frames at the link layer.

Table 1: ARQ Mechanism for QS-CD

Steps	Details
Source	Retry counter of each frame is initialized to zero (1) A new frame is transmitted by the source to the BS and partner in its own multiple access channel (source's channel) with bit energy $P_S = P_1/2$ (2) In the next time slot (a) If the time slot is 2 or it receives a ACK, go to 1) (b) If the retry counter does not exceed the maximum retry limit L, the corrupted (NAK received) frame is re-transmitted in the source's channel with bit energy $P_P = P_2/2$, retry counter is increased by 1 and go to 2) (c) Otherwise, the frame is dropped and go to 1)
Partner	If the partner receives the frame correctly, in the nest time slot, received frame is forwarded (DF) using partner's channel with bit energy $P_P = P_2/2$. Otherwise, partner forwards the received signal (AF) using its channel with bit energy $P_P = P_2/2$ in our proposed method or remains silent in method of Mahinthan *et al.* (2009)
Destination	At end of each time slot from second time slot, the message signal received from the source and the partner is combined by the BS using MRC. Depending on the received frame correctness, an ACK or a NAK is sent in the feedback channel to the source

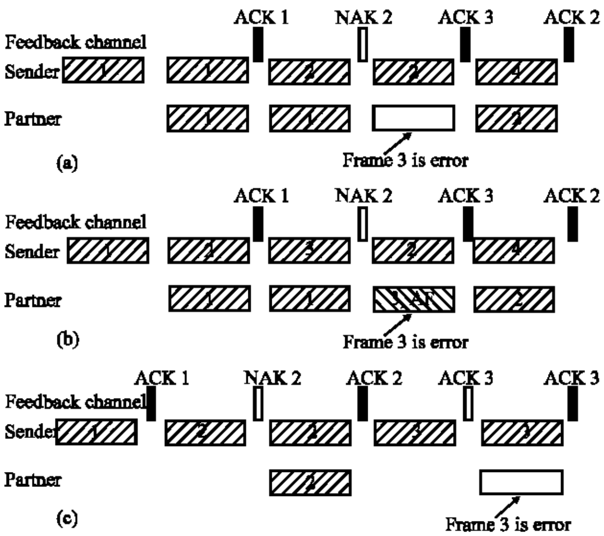

Fig. 2: CD-ARQ Scheme, (a) QS-DF-ARQ Scheme in (Mahinthan *et al.*, 2009), (b) Scheme proposed in this study and (c) STBC Scheme by Dai and Litaief (2005)

Signal received by the partner and destination: Firstly, the sender broadcasts the signal and the signals received at the partner and destination at time t are given by:

$$r_{SP}(t) = \sqrt{P_S}h_{SP}(t)x(t) + n_P(t) \quad (3)$$

$$r_{SD}(t) = \sqrt{P_S}h_{SD}(t)x(t) + n_D(t) \quad (4)$$

where, P_S is the transmitted power of the sender, $h_{SP}(t)$ and $h_{SD}(t)$ are the Nakagami fading channel coefficient of sender-partner link (with fading figure m_{SP}, signal power Ω_{SP} and maximum Doppler frequency f_{SP}) and sender-destination link (with fading figure m_{SD}, signal power Ω_{SD} and maximum Doppler frequency f_{SD}), respectively, x(t) is the symbol transmitted by the sender at time t and $n_P(t)$ and $n_D(t)$ are the additive white Gaussian noise at the partner and the destination, respectively, with zero mean and two-side power spectral density $N_0/2$.

If the partner receives the information correctly, DF scheme is used and the signal arriving at the destination can be written as:

$$r_{RD}(t+T_f) = \sqrt{P_P}h_{PD}(t+T_f)x(t) + n_D(t+T_f) \quad (5)$$

where, P_P is the transmitted power of the partner, T_f is the frame duration, $h_{PD}(t)$ is the Nakagami fading channel coefficient of partner-destination link (with fading figure m_{PD}, signal power Ω_{PD} and maximum Doppler frequency f_{PD}).

If the frame received at the partner is error, AF scheme is used, the signal arriving at the destination can be written as:

$$r_{RD}(t+T_f) = A\sqrt{P_P}h_{PD}(t+T_f)r_{SP}(t) + n_D(t+T_f) \quad (6)$$

where, A is the amplifying gain of the partner and

$$A = \sqrt{\frac{1}{N_0 + x(t)|h_{SP}(t)|^2}}$$

By using the MRC technique, the destination combines the received signal from the partner in the second frame and the received signal from the sender in the first frame. If DF scheme is used, the combined signal power can effectively be modeled as a Nakagami distributed function and the parameters can be derived as (Mahinthan *et al.*, 2009):

$$m_C = m_{SD} + m_{PD} \quad (7)$$

$$\Omega_C = \sqrt{(m_{SD} + m_{PD})\left(\frac{P_S^2\Omega_{SD}^2}{m_{SD}} + \frac{P_P^2\Omega_{PD}^2}{m_{PD}}\right)} \quad (8)$$

And if AF is used, the combined signal power has no exact expression, but the combined channel is better than non-cooperation channel anytime (Laneman *et al.*, 2004).

System performance: We assume that a sender always has a packet to transmit and it is assumed that the channel does not change in duration of a frame T_f. The metrics of interest in the performance evaluation of the DF+AF scheme, NCD-ARQ scheme and other CD schemes are channel efficiency in physical layer, throughput and PLR in link layer.

Channel efficiency is defined in the frame level as the ratio of the sum of error free frames to the total number of frames transmitted. The packet that was generated by the source cannot be transmitted in one frame in the physical layer; therefore, the packet is usually fragmented. We assume that a fixed-size packet from the upper layers is fragmented to N frames in the data link layer. Therefore, channel efficiency μ is equivalent to the probability of the system being in a good state and it can be expressed as:

$$\mu = p(SNR > SNR_T) = \frac{1}{\Gamma(m)}\Gamma\left(m, \frac{m}{\overline{\gamma}}SNR_T\right) \quad (9)$$

where, $\overline{\gamma}$ is the average SNR at the partner or destination and $\Gamma(\cdot,\cdot)$ is the incomplete gamma function.

For QS-DF-ARQ scheme (Mahinthan *et al*., 2009), the channel efficiency μ_{DF} can be expressed as:

$$\begin{aligned}\mu_{DF} &= P(SNR_{SP} > SNR_T)P(SNR_{SD} + SNR_{RD} > SNR_T) \\ &+ P(SNR_{SP} < SNR_T)P(SNR_{SD} > SNR_T)\end{aligned} \quad (10)$$

and for the proposed DF+AF method, the channel efficiency μ_{DAF} can be expressed as:

$$\begin{aligned}\mu_{DAF} &= P(SNR_{SP} > SNR_T)P(SNR_{SD} + SNR_{RD} > SNR_T) \\ &+ P(SNR_{SP} < SNR_T)P(SNR_{SD} + SNR_{SRD} > SNR_T)\end{aligned} \quad (11)$$

where, SNR_{SRD} is the SNR of the sender-partner-destination link in AF cooperation scheme, it is always a positive number. So, μ_{DAF}>μ_{DAF} is always available over the same channel state.

The PLR is defined by the ratio of the sum of dropped packets to the total number of packets transmitted. Each frame is retransmitted until it is successfully received or the number of retransmission attempts exceeds L and for a pocket to be successfully transmitted, all the frames must successfully be transmitted.

The throughput of the system is given by the ratio of the total number of packets that was successfully transmitted to the total number of slots that was used in this paper. Let Y (t) denote the number of packets that was successfully transmitted in time duration t. The average throughput ζ is given by:

$$\zeta = \lim_{t\to\infty}\frac{Y(t)}{t} = \frac{1-PLR}{T_p}\text{packet/slot} \quad (12)$$

where, T_p is the average time to transmit a pocket and $T_p \approx N \times \overline{T}_f$, $\overline{T}_f$, is the average time to transmit a frame.

NUMERICAL RESULTS

Here, the analysis of the proposed DF+AF scheme is validated by numerical results. In addition, the performance of the proposed DF+AF scheme is compared with that of the NCD-ARQ (Non-cooperation), QS-DF-ARQ and the STBC schemes. For simulation, we first generate the correlated Rayleigh fading traces and the use the efficient method proposed in (Beaulieu and Cheng, 2005) to generate correlated Nakagami-m fading envelope from the generated Rayleigh traces. The Nakagami fading figures m_{SP} = 2, m_{SD} = 1 and m_{PD} = 1, normalized Doppler frequency f_dT_f = 0.1 for all links. By defining the noise power spectral density N_0 = 1, the average signal power can be written as $P_S\Omega_{SP} = SNR_{SP}$, $P_S\Omega_{SD} = SNR_{SD}$, $P_P\Omega_{PD} = SNR_{PD}$, normalized average SNRs SNR_{SP}/SNR_T = 5 dB, SNR_{SD}/SNR_T = 5 dB and SNR_{PD}/SNR_T = 5dB, number of frames per packet N = 100 and a retry limit of a frame L = 4, if there are no special explanation.

Channel efficiency of various systems: Channel efficiency of various systems is simulated first, which is shown in Fig. 3. In Fig. 3a and b, the channel efficiency of DF+AF is better than that of DF and NCD and improves when the fading figure m_{PD} is changed from 1 to 2. This is because the frame error rate decreases with improving cooperative channels. In Fig. 3c and d, the DF+AF scheme is better than the DF scheme and better than NCD scheme when the normalized SNRs are greater than 0 dB. The analytical study of the NCD and DF schemes are validated by simulations in Fig. 3.

Simulations of link layer performance: From Fig. 4 to 13 are simulations of link layer performance, including PLR and throughput.

Figure 4 and 5 are the simulations of PLR and throughput for various maximum numbers of retransmissions L. We can see when L>4, the performance increases little, so L = 4 is studied below. Figure 6 and 7 are the simulations for various frame numbers N_f in a packet. In Fig. 6 and 7, the proposed DF+AF scheme is better than DF scheme.

Figure 8 and 9 are simulations for SNR_{SD}/SNR_T varying -4-10 dB, the DF+AF scheme gives lower PLR and higher throughput than DF, STBC and Non-cooperation schemes in all cases. Figure 10 and 11 are

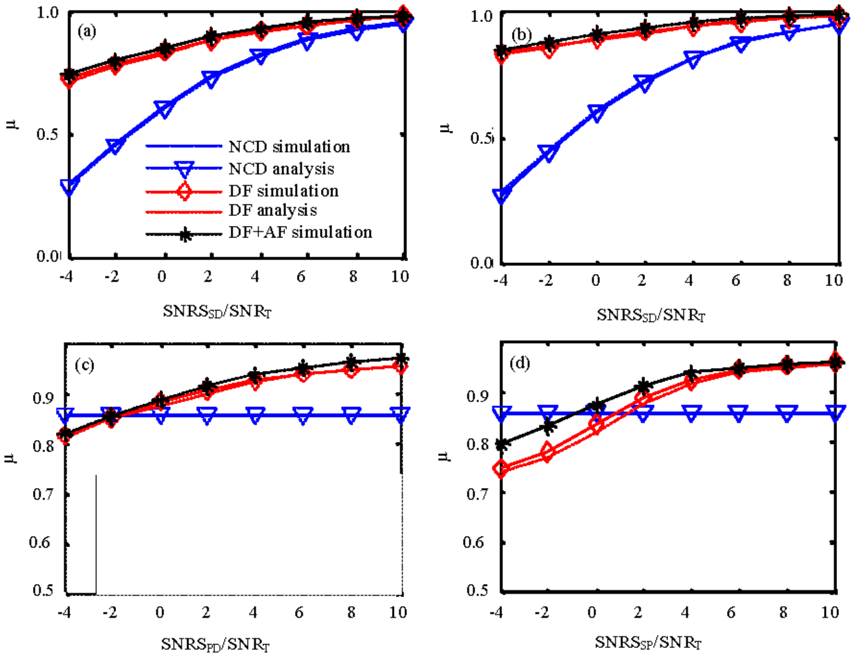

Fig. 3: Channel efficiency of the proposed scheme compared with the non-cooperative and DF schemes

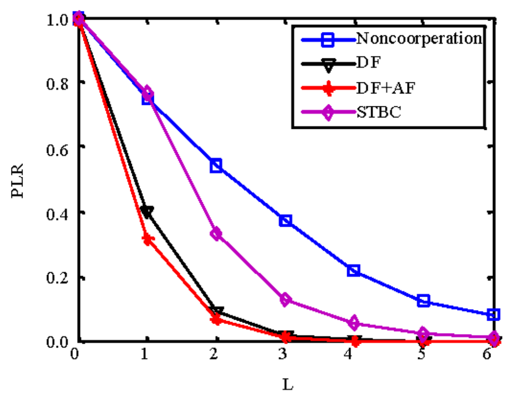

Fig. 4: PLR comparision for various L

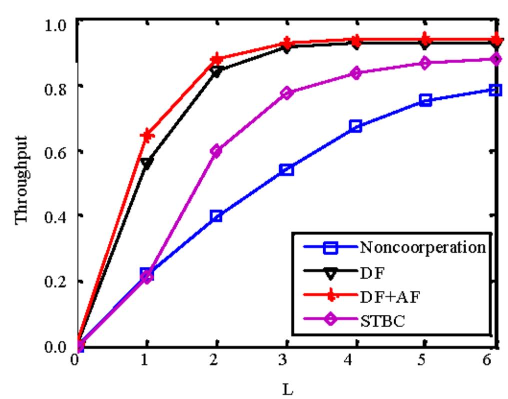

Fig. 5: Throuhgput comparision for various L

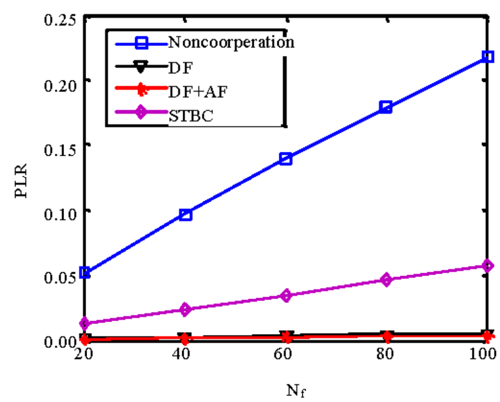

Fig. 6: PLR comparision for various N_f

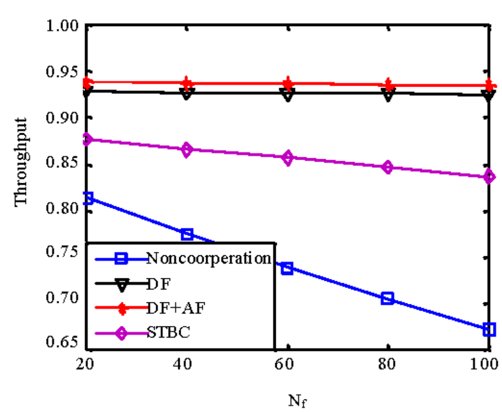

Fig. 7: Throuhgput comparision for various N_f

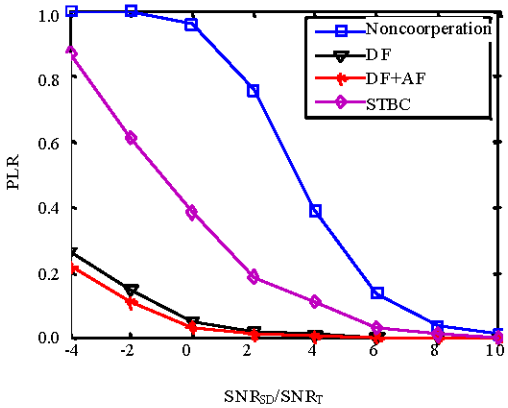

Fig. 8: PLR comparision for SNR_{SD}/SNR_T varying –4~10 dB

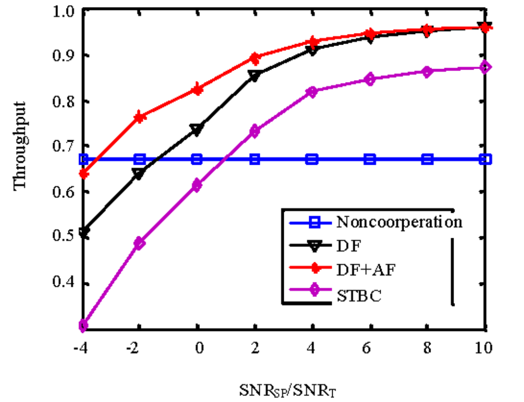

Fig. 11: Throuhgput comparision for SNR_{SP}/SNR_T varying -4~10 dB

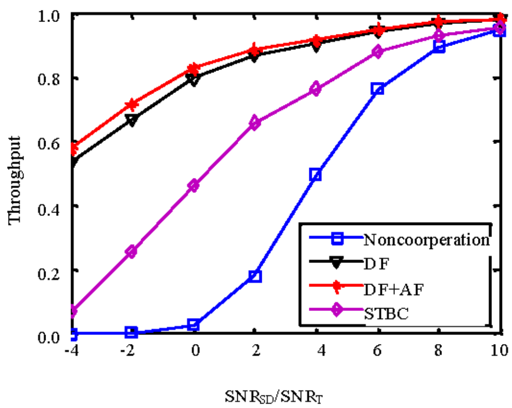

Fig. 9: Throuhgput comparision for SNR_{SD}/SNR_T varying -4~10 dB

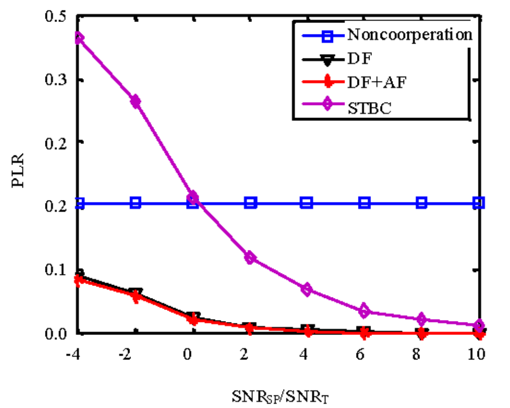

Fig. 12: PLR comparision for SNR_{PD}/SNR_T varying -4~10 dB

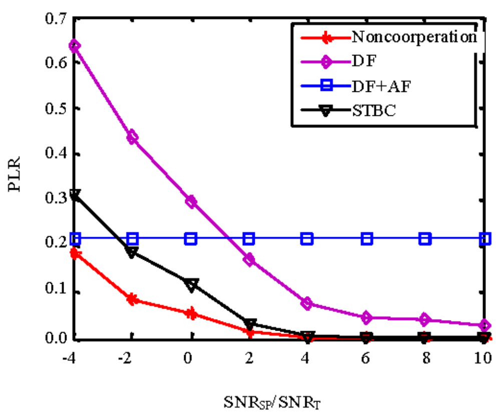

Fig. 10: PLR comparision for SNR_{SP}/SNR_T varying -4~10 dB

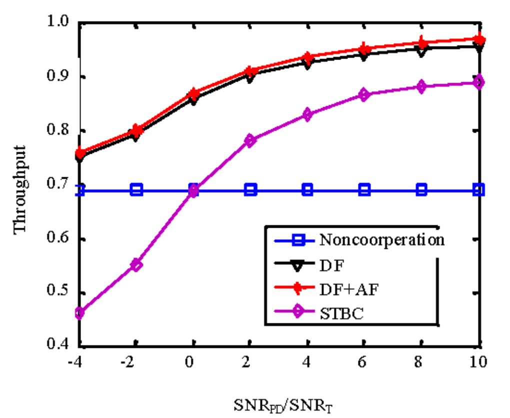

Fig. 13: Throuhgput comparision for SNR_{PD}/SNR_T varying -4~10 dB

simulations for SNR_{SP}/SNR_T varying -4-10 dB, the DF+AF scheme gives lower PLR and higher throughput than DF scheme in all cases. Figure 12 and 13 are simulations for SNR_{PD}/SNR_T varying -4-10 dB, the DF+AF scheme gives lower PLR and higher throughput than DF scheme in all cases, too.

Based on Fig. 8-13, the proposed scheme is better than the DF scheme in (Mahinthan *et al.*, 2009) and the STBC scheme in all cases and the Non-cooperation scheme when the SNR_{SP} and SNR_{PD} are better than a threshold.

DISCUSSION

Through the results in Fig. 3-13, we can find the proposed scheme can transmit more frames or packets than previous cooperative schemes. It means that we can obtain higher spectral efficiency using the proposed scheme comparing with other cooperative schemes and non-cooperative scheme. The major contribution of this paper is that we combine the AF and DF schemes in a cooperative communication system. Compared with the DF scheme, the proposed DF+AF scheme can use frequency spectrum resources more sufficiently because the partner will relay the information from sender in every frame. However, in the DF scheme, the partner keeps silent when it can not decode the received information correctly, which is waste of frequency spectrum resources. When the partner can decode received signal correctly, the partner use DF scheme in proposed method, which will not amplify the noise as in AF scheme. Therefore, the proposed DF+AF scheme combines the merits of DF and AF scheme and it can provide better performance than DF scheme. However, through the proposed scheme, more energy is consumed than DF scheme, so it is the tradeoff between energy and frequency. And a SNR threshold can be set up, when the received SNR in partner larger than the threshold, AF cooperation is used, which can get the tradeoff between performance and energy.

CONCLUSION

We have proposed a DF+AF scheme for cooperative diversity systems. The proposed scheme used AF cooperative scheme when the partner can not receive the information from the sender correctly and used DF scheme on the contrary. The cross-layer performances of the proposed scheme over Nakagami-m fading channels are better than the QS-DF-ARQ scheme in all cases and it outperforms other schemes when the sender is cooperating with a partner who provides a good sender to partner and partner to destination link. And only 1 bit information should be transmitted for signing the transmission scheme.

ACKNOWLEDGMENTS

This study is supported by the National Basic Research Program (also called 973 Program) of China under Grant No. 2007CB310601 and the National Natural Science Foundation of China under Grant No. 60872016.

REFERENCES

Beaulieu, N.C. and C. Cheng, 2005. Efficient nakagami-m fading channel simulation. IEEE Trans. Veh. Technol., 54: 413-424.

Bletsas, A., A. Khisti, D.P. Reed and A. Lippman, 2006. A simple cooperative diversity method based on network path selection. Select. Areas Commun. IEEE J., 24: 659-672.

Dai, L. and K.B. Litaief, 2005. Cross-layer design for combing cooperative diversity with truncated ARQ in ad-hoc wireless networks. Proceedings of IEEE Globecom, Dec. 2, St. Louis, USA., pp: 3175-3179.

Laneman, J.N., N.C.T. David and G.W. Wornell, 2004. Cooperative diversity in wireless networks: Efficient protocols and outage behavior. IEEE Trans. Inform. Theory, 50: 3062-3080.

Mahinthan, V., J.W. Mark and X. Shen, 2007a. Maximizing cooperative diversity energy gain for wireless networks. IEEE Trans. Wireless Commun., 6: 2530-2539.

Mahinthan, V., J.W. Mark and X. Shen, 2007b. A cooperative diversity scheme based on quadrature signaling. IEEE Trans. Wireless Commun., 6: 41-45.

Mahinthan, V., J.W. Rutagemwa, H. Mark and X. Shen, 2009. Cross-layer performance study of cooperative diversity system with ARQ. IEEE Trans. Veh. Technol., 58: 705-719.

Nosratinia, A. and T.E. Hunter, 2007. Grouping and partner selection in cooperative wireless networks. IEEE J. Sel. Areas Commun., 25: 369-378.

Sendonaris, A., E. Erkip and B. Aazhang, 2003. User cooperation diversity-Part I: System description. IEEE Trans. Commun., 51: 1927-1938.

Zhou, Z., S. Zhou, J. Cui and S. Cui, 2008. Energy-efficient cooperative communication based on power control and selective single-relay in wireless sensor networks. IEEE Trans. Wireless Commun., 7: 3066-3078.