WSN환경에서 Decode-and-Forward 협력통신의 시스템 최적화 및 최대전송률과 저전력에 관한 연구

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요 약

본 논문에서는 WSN(Wireless Sensor Network)에서 복호 후 재전송(Decode-and-forward) 협력통신 방식에서 데이터 전송률이 1/2가 되는 것을 극복하여, 최대전송률이 되는 협력 프로토콜을 제안하였다. 기존의 협력프로토콜 시스템에서는 소스가 두 타임 슬롯 동안 두 데이터를 전송하게 되면 다이버시티 이득은 얻지 못하고, 다이버시티 이득을 얻기 위하여 타임 슬롯을 증가시키면 전송률이 낮아지게 된다. 본 논문의 알고리즘은 각각의 데이터를 직교주파수로 구분하고 좌표회전 기법을 이용하여 최대전송률과 다이버시티 이득을 동시에 얻을 수 있다. 또한, 센서노드와 릴레이의 거리에 따른 성능분석을 하였고 시스템의 성능에 영향을 끼치는 요소들을 컴퓨터 모의실험을 통하여 최적화 시켰다. 최적의 거리 d=0.2에서 BER이 10-2일 때 직접 전송일 경우보다 7dB까지 멀티 홉보다 5dB 정도의 네트워크 전력이 절약되는 것을 확인할 수 있다. 따라서 무선 센서네트워크의 전력을 감소시며 데이터 전송률을 증가시키는 시스템을 제안하였다.

키워드 : 협력통신, 좌표회전, 복호 후 전송, 저전력

System Optimization, Full Data Rate and Transmission Power of Decode-and-Forward Cooperative Communication in WSN

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ABSTRACT

In conventional cooperative communication data rate is 1/2 than non cooperative protocols. In this paper, we propose a full data rate DF (Decode and Forward) cooperative transmission scheme. Proposed scheme is based on time division multiplexing (TDM) channel access. When DF protocol has full data rate, it can not obtain diversity gain under the pairwise error probability (PEP) view point. If it increases time slot to obtain diversity gain, then data rate is reduced. The proposed algorithm uses orthogonal frequency and constellation rotation to obtain both full data rate and diversity order 2. Moreover, performance is analyzed according to distance and optimized components that affect the system performance by using computer simulation. The simulation results revealed that the cooperation can save the network power up to 7dB over direct transmission and 5dB over multi-hop transmission at BER of 10^{-2}. Besides, it can improve date rate of system compared with the conventional DF protocol.

Key Words : Cooperative Transmission, Constellation Rotation, Decode-and-Forward, Power Consumption

1. Introduction

In wireless channels, reliable communication is difficult due to fading. A feasible solution is to take full advantage of idle SNs (sensor node), namely relays, in the vicinity of the transmitting node to relay the original signal to its destination. Cooperative transmission not only gets benefit from path-loss reduction but also exploits antennas of other relays in the network to obtain diversity gain without the physical antenna arrays. In addition, size limitation of a node which requires each SN to be equipped with single-antenna makes such a solution very appropriate in WSN scenario. The ways the idle SNs process the signals received from a desired node are known as cooperative protocols [1]-[3].

※ This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Assessment)(IITA-2007_C1090-0701-0039).
※ This work was supported by the Korea Science and Engineering Foundation(KOSEF) grant funded by the Korea government(MOST) (No. R01-2007-000-20400-0)
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논문접수 : 2007년 8월 8일, 심사완료 : 2007년 12월 12일

So far, there are three basic cooperative protocols: amplify-and-forward (AF) [1], decode-and-reencode (DR) [2] and decode-and-forward (DF) [3] has been proposed AF requires inter-user CSI (Channel State Information) available at the destination which is hard to obtain, and suffers noise enhancement at the relays that degrades BER performance. In addition, DR used convolutional codes, turbo codes and TCM (Trellis Coded Modulation) achieves the best performance among three protocols but so complicated in encoding and decoding, thus preventing from implementing on SNs. DF appears to be a proper choice for cooperation in WSNs because it demonstrates the lowest complexity (each receiver only needs CSI of the channel it is listening).

We propose a protocol to improve performance and data rate using orthogonal frequency and constellation rotation. The proposed system adopts DF scheme based on time division multiplexing (TDM) as channel access. When DF protocol has a maximum data rate, conventional DF protocol can not obtain diversity gain in the pairwise error probability (PEP) view point.

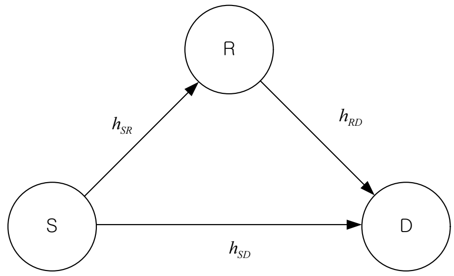
The remainder of the paper is organized as follows. In Section 2, we introduce the proposed system model and protocols. Section 3, we derive analysis of cooperation diversity. Section 4 shows the simulation results with their explanation. Finally, Section 5 provides our conclusions.

2. Proposed system model and protocol

2.1 System model

Multi-hop transmission has to pass through several relays before reaching the destination. The relay's role is to simply decode the data it receives from the preceding node and again encode the message prior to retransmission to the next node. The destination detects the original data only based on the signal received from the last node (nearest to the destination). It is shown that this protocol can only extend range or save transmit power but achieves no diversity gain (diversity order of 1)

Cooperative protocol is an extension of the multi-hop protocol where the receiver combines the data from the desired source node and all its relays instead of only from the last relay as for the multi-hop protocol. A wide variety of cooperative transmission protocols were proposed but a majority requires the channel estimation, thus leading to an additional increase in information processing energy. However, they can still bring many simultaneous advantages such as diversity gain, coverage extension, energy saving. The maximum diversity order that these protocols can achieve equal the total number of cooperating nodes.



(Fig. 1) Cooperative sensor network model

Consider cooperative transmission in a wireless sensor network as shown in (Fig. 1) where the information is transmitted from a source S to a destination D with the assistance of a relay R. All terminals are equipped with single-antenna transceiver and sharing the same frequency band under investigation. In addition, terminals can not transmit and receive signal at the same time and frequency to mitigate the implementation complexity. Towards this end, we adopt time division multiplexing (TDM) for channel access in this paper. An interesting feature of the proposed cooperation is that it only takes place in the time slot assigned for *S*. Therefore instead of direct transmission with *T* time unit for each data symbol, the cooperative transmission is only allowed to send each data symbol with *T*/2 time unit to keep the same bandwidth efficiency as direct transmission counterpart.

2.2 Proposed Protocol

Cooperation process consists of two phases. In phase 1, S broadcasts symbol x_1 with normalized unit energy to both R and D. Relay decodes received data from S. In phase 2, S and R send data to D simultaneously. For S, it transmits next data x_2 to D. For R, it retransmits received data from S at phase 1. This processing is shown in (Fig. 2) D can divide each data by using orthogonal frequency F_1, F_2.

Therefore, the sequence of signals received at R and D have the forms as follows

$$y_{R1} = \sqrt{E_{SR}} h_{SR} x_1 + n_{R1} \quad (1)$$

$$y_{D1} = \sqrt{E_{SD}} h_{SD} x_1 + n_{D1} \tag{2}$$

$$y_{D2} = \sqrt{E_{RD}} h_{RD} \hat{x}_1 + \sqrt{E_{SD}} h_{SD} x_2 + n_{D2} \tag{3}$$

where

y_{kj} is received signal at terminal k from the source S during symbol duration j; $k \in \{R,D\}$, $j \in \{1,2\}$.

n_{kj} is zero-mean additive noise sample of variance p_k at terminal k in symbol duration j.

E_{ij} is average transmit power by $i,j \in \{S,R,D\}$.

We assume that the channel between source and relay and between relay and the destination are independent of each other. Moreover, all channels experience frequency flat Rayleigh fading. Due to Rayleigh fading, h_{ij} are independent zero-mean complex Gaussian random variables (IZMCGRVs). We denote h_{SR}, h_{SD}, h_{RD} as variances of path gains of S-R channel, S-D channel, R-D channel, respectively.

If the relay decodes the received signal perfectly, we represent Eq. (3) as follows

$$y_{D2} = \sqrt{E_{RD}} h_{RD} x_1 + \sqrt{E_{SD}} h_{SD} x_2 + n_{D2} \tag{4}$$

Then, we obtain the matrix from Eq. (2) and (4) as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \tag{5}$$

where

$\mathbf{x} = [x_1 \;\; x_2]^T$ is a symbol vector that is transmitted from S, $\mathbf{y} = [y_{D1} \;\; y_{D2}]^T$ is symbol vector that receive at D. H is represented by channel gain matrix as follow

$$\mathbf{H} = \begin{bmatrix} \sqrt{E_{SD}} h_{SD} & 0 \\ \sqrt{E_{RD}} h_{RD} & \sqrt{E_{SD}} h_{SD} \end{bmatrix} \tag{6}$$

From Eq. (5) and (6) have the same form as cooperative transmission

Moreover, in (Fig 2) and Eq. (5), two symbols are transmitted during two time units. Total data rate becomes *2/2=1* as DT(Direct Transmission). But channel gain matrix in Eq. (6) can't obtain diversity gain, since H is not a complete matrix.

We suggest an algorithm that uses constellation rotation for diversity gain. Its system model can be represented by the following equation

Direct Transmission		X_1		X_2	
Cooperative Transmission	S	X_1F_1	X_2F_1	X_3F_1	X_4F_1
	R	X_1F_1 R_x	X_1F_2 T_x	X_3F_1 R_x	X_3F_2 T_x
	D	X_1F_1 R_x	$(X_1F_2+X_2F_1)R_x$	X_3F R_x	$(X_3F_2+X_4F_1)R_x$

(Fig. 2) Direct transmission and Cooperation processing model (Tx: Transmit, Rx: Receive, F_1, F_2: Orthogonal Frequency)

$$\mathbf{y} = \mathbf{H}\boldsymbol{\Theta}\mathbf{x} + \mathbf{n} = \widetilde{\mathbf{H}}\mathbf{x} + \mathbf{n} \tag{7}$$

The unitary vector $\boldsymbol{\Theta}$ denotes the following equation

$$\boldsymbol{\Theta} = \frac{1}{\sqrt{1+\theta^2}} \begin{bmatrix} \theta & 1 \\ -1 & \theta \end{bmatrix} \tag{8}$$

Substituting H and $\boldsymbol{\Theta}$ from (7), we obtain $\widetilde{\mathbf{H}} = [\widetilde{\mathbf{h}}_1 \;\; \widetilde{\mathbf{h}}_2]$ as

$$\widetilde{\mathbf{h}}_1 = \frac{1}{\sqrt{1+\theta^2}} \begin{bmatrix} \theta\sqrt{E_{SD}} h_{SD} \\ \theta\sqrt{E_{RD}} h_{RD} - \sqrt{E_{SD}} h_{SD} \end{bmatrix} \tag{9}$$

$$\widetilde{\mathbf{h}}_2 = \frac{1}{\sqrt{1+\theta^2}} \begin{bmatrix} \sqrt{E_{SD}} h_{SD} \\ \sqrt{E_{RD}} h_{RD} + \theta\sqrt{E_{SD}} h_{SD} \end{bmatrix} \tag{10}$$

In the channel gain matrix, column vectors have same variance and elements are not zero. This matrix is a complete matrix to obtain diversity.

3. Diversity Analysis

We assume that the relay can decode received data correctly and this system can estimate channel exactly. D detects and decodes the original data from the received data by using maximum-likelihood (ML) detector.

$$\hat{x} = \arg\min_{x} \left\| \mathbf{y} - \mathbf{H}\mathbf{x} \right\|^2 \tag{11}$$

where, $\|\bullet\|$ means the Frobenius norm. We derive PEP about channel gain matrix $\widetilde{H}$ by using Eq. (11). The probability of detecting x_j symbol when transmitted symbol was x_i, can be given as

$$P(x_i \to x_j|\widetilde{\mathbf{H}}) = \Pr\left[\left\|\mathbf{y} - \widetilde{\mathbf{H}}\mathbf{x_i}\right\|^2 \geq \left\|\mathbf{y} - \widetilde{\mathbf{H}}\mathbf{x_j}\right\|^2 \middle| \widetilde{\mathbf{H}}\right] = Q\left(\sqrt{\frac{\left\|\widetilde{\mathbf{H}}(x_i - x_j)\right\|^2}{2N_0}}\right) \quad (12)$$

where, $Q[\bullet]$ is the Q-function. The relation between H and column vector is given by $\|\widetilde{\mathbf{H}}\|^2 = \|\widetilde{\mathbf{h}}_1\|^2 + \|\widetilde{\mathbf{h}}_2\|^2$. The average PEP is equal to the following formula

$$P(x_i \to x_j) = E_H\left[Q\left(\sqrt{\frac{\left\|\widetilde{\mathbf{H}}(x_i - x_j)\right\|^2}{2N_0}}\right)\right] \quad (13)$$

where, $E[\bullet]$ is an expectation function. So, we can obtain the PEP upper bound from Chernoff bound $Q(x) \leq \exp(-x^2/2)$ as

$$P(x_i \to x_j) \leq E_H\left[\exp\left(\frac{\left\|\widetilde{\mathbf{H}}(x_i - x_j)\right\|^2}{2N_0}\right)\right] = M_{\Delta'}\left(-\frac{1}{4N_0}\right) \quad (14)$$

where, random variable Δ' is equal to $\|\widetilde{\mathbf{H}}(x_i - x_j)\|^2$ and $M_{\Delta'}$ is a moment generating function (MGF) of Δ'. We explain the Eq. (14) as follows

$$P(x_i \to x_j) \leq M_{\Delta'}\left(-\frac{1}{4N_0}\right) = E_H\left[\exp\left(-\lambda\frac{\|\widetilde{\mathbf{h}}_1\|^2}{4N_0}\right)\right] = \frac{1-\rho^2(\theta)}{\left(1+\lambda\frac{E_s}{2N_0}\left(1-\rho^2(\theta)\right)\right)^2 - \rho^2(\theta)} \quad (15)$$

where, the factor $\rho(\theta)$ is the correlation between $\frac{1}{1+\theta^2}\left|\theta\sqrt{E_{SD}}h_{SD}\right|^2$ and $\frac{1}{1+\theta^2}\left|\theta\sqrt{E_{RD}}h_{RD} - \sqrt{E_{SD}}h_{SD}\right|^2$. At a high SNR we can obtain diversity order as follows

$$\text{diversity order} = \lim_{SNR\to\infty} -\frac{\log P(x_i - x_j)}{\log(SNR)} = 2 \quad (16)$$

In the final analysis, we can see that this cooperative transmission through constellation rotation scheme can improve diversity gain.

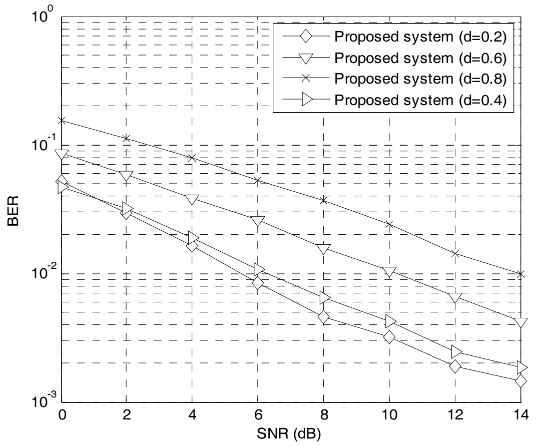
4. Simulation Result

In this section, we investigate the performances of three transmission protocols (Direct Transmission, Multi-hop, Cooperative communication) in wireless sensor network. We consider $Q=3$, $\theta=2.05$ for all simulations.

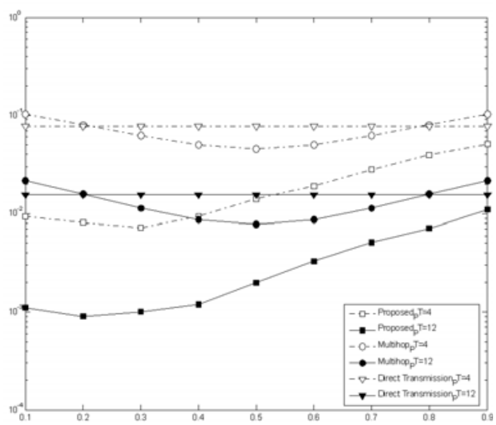
Network geometry is examined where the relay is located on a line between S and D. The direct path length S-D is normalized to be 1. We also denote d as the distance between S and R. Therefore, $d_{RD}=1-d$.

In (fig 3), we verify the performance for d={0.2, 0.4, 0.6, 0.8} with Monte-Carlo simulations. We can see that BER performance of the proposed cooperative transmission protocol significantly depends on the relay positions.

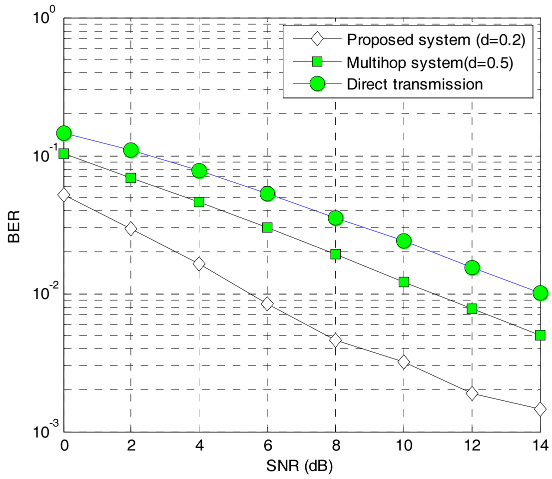
(Fig. 4) studies the influence of the relay location on



(Fig. 3) BER comparison between relay positions



(Fig. 4) BER performance versus d



(Fig. 5) BER performance of transmission protocols

the performance of cooperative protocol for two different values of total transmit power P_T of 4dB and 12dB. It is realized that the multi-hop transmission is better than the direct one only when the relay is placed in the interval [0.2, 0.8] while the proposed protocol always outperforms the direct transmission. (Fig. 4) also illustrates that the optimal relay position for the multi-hop transmission is at the center of S-D line since it presents a good trade-off between good receive conditions for the relay and transmit power savings. Moreover, the cooperative protocol exposes its considerable superiority to comparable ones when it is closer to S and attains the best performance at roughly d=0.2.

(Fig. 5) compares the optimal performances of transmission protocols. At the target BER of 10^{-2}, the proposed protocol can save the system power up to 5.5dB and 8.5dB in compare with the multi-hop and direct cases, respectively. In addition, power savings keeps increasing correspondingly to the higher performance requirement, which is represented by the steeper slope of BER curve in the cooperative case than those in the other cases.

5. Conclusion

In this paper, we proposed the cooperative transmission scheme that can obtain full data rate and diversity order 2 by using constellation rotation. Moreover, the simulation results showed that the proposed protocol significantly increases the channel utilization efficiency and power efficiency. The power savings achieved by cooperation is equivalent to prolonging sensor network lifetime and better satisfying the critical design condition of WSNs.

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