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무선 센서 네트워크에서 1-2-1 협력 프로토콜에 관한 연구

Performance Analysis of 1-2-1 Cooperative Protocol in Wireless Sensor Networks

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요 약 기존의 1-1-1 협력 프로토콜은 멀티 홉이 가지고 있는 경로손실감소 이득과 함께 MIMO와 동일한 공간 다이버시티를 제공한다. 이를 통해 싱글 홉, 멀티 홉보다 뛰어난 정보의 신뢰도 및 에너지 소비 감소를 얻을 수 있다. 하지만 기존의 1-1-1 협력 프로토콜은 단일의 협력 중계기를 사용하므로 경로손실감소 이득과 다이버시티 이득 계수가 2로 제한되어 있다. 따라서 본 논문에서는 두개의 협력 중계기 R1, R2를 사용한 1-2-1 협력 프로토콜을 제안한다. 1-2-1 협력 프로토콜은 경로손실감소 이득을 높이고 계수가 3인 다이버시티 이득을 얻는다. 또한, 협력 중계기 R2에서도 계수가 2인 다이버시티 이득을 얻을 수 있다. 협력 중계기는 DF (Decode and Forward)와 DR (Decode and Reencode) 방식을 사용하여 1-2-1 DF 또는 DR 협력 프로토콜을 형성하고, 클러스터링 기반의 무선 센서 네트워크(WSNs)에 적용한다. 제안한 프로토콜의 성능평가를 위해 레일리 페이딩과 AWGN (Additive White Gaussian Noise) 채널이 합해진 채널에서 모의실험을 한다.

Abstract Conventional 1-1-1 cooperative protocol offers path-loss gain as advantage of multi-hop and spatial diversity which is equivalent to MIMO system. This protocol is enable to get higher reliability and reduction of power consumption than those of the single-hop or multi-hop. But the 1-1-1 cooperative protocol get only the diversity order 2 and limited path-loss reduction gain because this protocol has a single cooperative relay. We propose 1-2-1 cooperative protocol using two cooperative relays R1, R2. The 1-2-1 cooperative protocol can improve path-loss reduction and increase diversity order 3. Moreover, the cooperative relay R2 attains diversity order 2. The signaling method in transmission uses DF (Decode and Forward) or DR (Decode and Reencode) and 1-2-1 DF/DR cooperative protocol are applied to clustering based wireless sensor networks (WSNs). Simulations are performed to evaluate the performance of the protocols under Rayleigh fading channel plus AWGN (Additive White Gaussian Noise).

Key Words : Cooperative protocol, WSNs, DF, DR, Diversity gain

Ⅰ. Introduction

In wireless communication, signal distortion due to multi-path propagation is a serious problem which can be mitigated using spatial diversity by deploying multiple antennas at transmitter and receiver. Therefore, MIMO system have been introduced. MIMO system has multi antennas at transmitter and receiver can increase amount of information that each antenna transmits each different information and also that system has the coding gain as diversity effect by using STC (Space Time Code). But it is difficult to apply multi antennas into wireless devices such as mobile phones, laptop computers, personal digital assistants

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(PDAs), senor and etc. Therefore, a new class called cooperative communication has been emerged. It is enables to exploit virtual multiple antenna among distributed single antenna wireless equipments.

Recently, cooperative protocol is issued in wireless communication fields and studied as follow. [1]-[5] introduce AF (amplify-and-forward), DF (decode-and-forward), DR (decode-and-reencode) as signaling process methods at cooperative relay. Results of simulation show the advantage of cooperative protocols that have better performance than those of direct transmission. [6] considers not only diversity gain but also path-loss reduction by placing the relay in between source and destination. Thus, the cooperative protocols are wireless communication technique to increase reliability of system and to attain energy saving. These advantages of cooperative protocol is very useful to be applied to wireless sensor networks (WSNs). However, the performance of the 1-1-1 cooperative protocols is restrictive that it have only diversity order 2 and limited path-loss reduction because of only using one relay. Here, this paper proposes 1-2-1 cooperative protocol that increase the advantage of the conventional protocols. The proposed 1-2-1 cooperative protocol uses two cooperative relays (R1 and R2) and gets higher path-loss reduction and diversity order 3 at D, while the 1-1-1 cooperative protocols get diversity order 2 [1]-[5]. Moreover, R2 gets diversity order 2. Thus, we can apply 1-2-1 cooperative protocol to clustering based WSNs. For convenience analysis, this paper shows the performances with only 2 relays but, the transmission method is applied to networks with the increasing number of relays such as 1-n-1[7].

The paper is organized as follows. Section Ⅱ presents the proposed 1-2-1 cooperative protocol and cluster based wireless sensor networks with the proposed protocol. Monte-Carlo simulations are performed in section Ⅲ to verify its validity and to compare the reference communications schemes. Finally, section Ⅳ summarizes and concludes this paper.

Ⅱ. Proposed 1-2-1 cooperative Protocol

1. protocol model

In this section, we propose 1-2-1 cooperative protocol in Fig. 1. To consider path-loss, a network geometry is examined where cooperative relays (R_1, R_l)

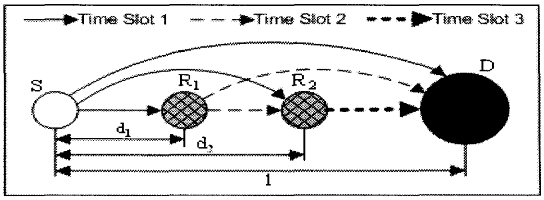

Fig. 1 1-2-1 cooperative protocol

lie on a straight line between source (S) and destination (D). The direct path length S-D is normalized to be 1. We also denote d_1, d_2 as the distance between S and R_1 or S and R_2, respectively.

All nodes equipped with single antenna transceiver and sharing the same bandwidth are under investigation. In addition, each node can not transmit and receive signal at the same time to mitigate implementation complexity since considerable attenuation over wireless channels and insufficient electrical isolation between transmit and receive circuitry make a node's transmitted signal dominate the signals of other nodes at its receiver input. Towards this end, we adopt time division multiplexing (TDM) for channel access in this paper.

The 1-2-1 cooperative protocol considers signaling method as DF or DR when the relays transmit data to next relay or D. S transmits its data to R_1, R_2 and D in time slot 1 (a solid line in fig. 1). In time slot 2, R_1 processes the received signal in accordance with signaling method (DF or DR) and then transmits the data to R_2 and D (a thin dotted line in Fig. 1). In the same time slot, The R_2 combines the received signal from R_1 with the previous signal from S in buffer of R_2

using MRC (Maximal Ratio Combining). Here, we get the diversity order 2. Then we recover the desired data by signaling process of R_2. In time slot 3, the R_2 transmits the recovered data to D (a thick dotted line in Fig. 1). The D also combines all received signal from S, R1 and R2 using MRC and then recovers the desired data using ML (maximum likelihood) criterion. For fair comparison, we allocate same total transmit power P_T to single-hop, multi-hop, 1-1-1 cooperative protocol and 1-2-1 cooperative protocol: the transmit power of single-hop P_S=P_T, each transmit power of using one relaying case P_S=P_R=P_T/2, each transmit power of using two relaying case P_S=P_{R1}=P_{R2}=P_T/3. The P_i denote transmit power at i.

2. channel model and Signal processing

Now, 1-2-1 DF cooperative protocol (R_1 and R_2 are DF) performs as follows.

- Time slot 1

$$At\ D:\ y_{SD}=\alpha_{SD}\sqrt{P_S}a+n_{SD} \quad (1)$$

$$R_1:\ y_{SR_1}=\alpha_{SR_1}\sqrt{P_S}a+n_{SR_1} \quad (2)$$

$$r_{R_1}=sign(Re(\alpha^*_{SR_1}y_{SR_1})) \quad (3)$$

$$R_2:\ y_{SR_2}=\alpha_{SR_2}\sqrt{P_S}a+n_{SR_2} \quad (4)$$

where: $a\in\{-1,1\}$ as BPSK modulated values and α_{ij} is the coefficient of the slow Rayleigh fading between transmitter i and receiver j, n_{ij} is AWGN (Additive White Gaussian Noise) sample at j. y_{ij} is the received data at j. sign(.) is a signum function. ∗ is conjugate function and Re(.) is real part of a complex number. r_j is the recovered data at j. Total transmit power of the system denotes P_T. If P_i is the transmit power of node i, P_S, P_{R1} and P_{R2} are P_T/3 while the each nodes of 1-1-1 cooperative protocol have P_T/2 individually. In the time slot 2, R_1 transmits the recovered data in (3) to R_2 and D.

- Time slot 2

$$At\ R_2:\ y_{R_1R_2}=\alpha_{R_1R_2}\sqrt{P_{R_1}}r_{R_1}+n_{R_1R_2} \quad (5)$$

$$y=\frac{\alpha^*_{SR_2}\sqrt{P_S}}{\sigma^2_{R_2}}y_{SR_2}+\frac{\alpha^*_{R_1R_2}\sqrt{P_{R_1}}}{\sigma^2_{R_2}}y_{R_1R_2} \quad (6)$$

$$r_{R_2}=sign(Re(y)) \quad (7)$$

$$D:\ y_{R_1D}=\alpha_{R_1D}\sqrt{P_{R_1}}r_{R_1}+n_{R_1D} \quad (8)$$

σ^2_j is variance of gaussian noise of j. We mention that the characteristic of the propose protocol attains diversity gain between S and D. Thus, R2 combines y_{SR_2} and $y_{R_1R_2}$ using MRC and we receive higher reliability data at R2.

- Time slot 3

$$At\ D:\ y_{R_2D}=\alpha_{R_2D}\sqrt{P_{R_2}}r_{R_2}+n_{R_2D} \quad (9)$$

$$a=\frac{\alpha^*_{SD}\sqrt{P_S}}{\sigma^2_D}y_{SD}+\frac{\alpha^*_{R_1D}\sqrt{P_{R_1}}}{\sigma^2_D}y_{R_1D}+\frac{\alpha^*_{R_2D}\sqrt{P_{R_2}}}{\sigma^2_D}y_{R_2D} \quad (10)$$

$$r_D=sign(Re(a)) \quad (11)$$

D combines y_{SD}, y_{R_1D} and y_{R_2D} and also uses MRC (10). Thus, we get diversity order 3 and the mixed signal is recovered data as 1, -1 by (11).

1-2-1 DR cooperative protocol (R_1 and R_2 are DR), S transmits coded data by using channel coding in communication system. R1 and R2 perform different signaling process in time slot 1. R1 recovers the desired data after (3) and then reencodes the data for retransmission. while, R2 saves the received signal in its buffer because R2 will receive another signal from R1 in time slot 2.

3. Cluster based cooperative protocols

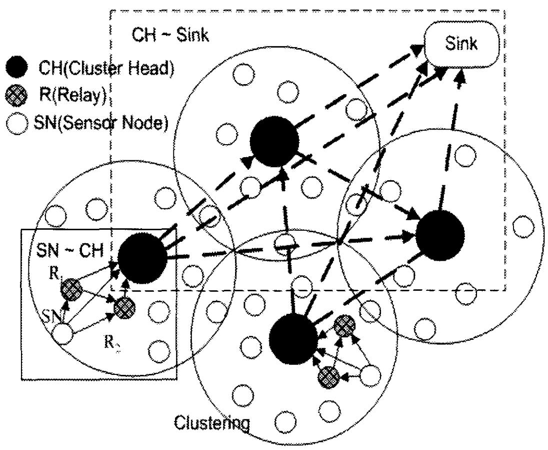

Fig. 2 Cluster based 1-2-1 DF/ DR cooperative protocol in WSNs

The 1-2-1 DR cooperative protocol consumes more energy than DF case because nodes require coding block and the energy consumption differ with code type. Consequently, in Fig. 2, we effectively apply 1-2-1 cooperative protocol to WSNs. Fig. 2 shows cluster based WSNs from sensor nodes to sink using 1-2-1 cooperative protocol. We assume that the cluster based networks from S to D has already organized at higher layers according to range of cluster head (CH) with propagation path and scheduling. The CHs have the larger power than that of sensor nodes. Therefore, we propose 1-2-1 DF cooperative protocol between sensor nodes (SNs) and CH because SNs have constraint resources. Moreover, 1-2-1 DR cooperative protocol with coding gain using cyclic code is used between CHs and Sink.

Ⅲ. Simulation Results

In this section, we perform Monte-Carlo simulation to evaluate the BER performance of the proposed system. The channels for simulation experience slow and frequency flat Rayleigh fading plus AWGN. For example, the amplitude of path gain α_{ij} between transmitter i and receiver j is Rayleigh distribution (equivalently, α_{ij}^2 is exponential random variable with mean λ_{ij}^2) and the phase Φ_{ij} has uniform distribution in the interval $[0, 2\pi]$ and they are constant during one packet period and change independently to the next packet.

We compare proposed 1-2-1 cooperative protocol with single-hop, multi-hop and 1-1-1 cooperative protocol. As we discussed in section Ⅱ, the BER performance varied according to d. Thus, we only consider the optimal distance of relay for each protocol.

- 1-1-1 DF multi-hop: d=0.5
- 1-1-1 DF cooperative protocol: d=0.2
- 1-2-1 DF multi-hop: d_1=0.4, d2=0.7
- 1-2-1 DF cooperative protocol: d_1=0.1, d_2=0.5

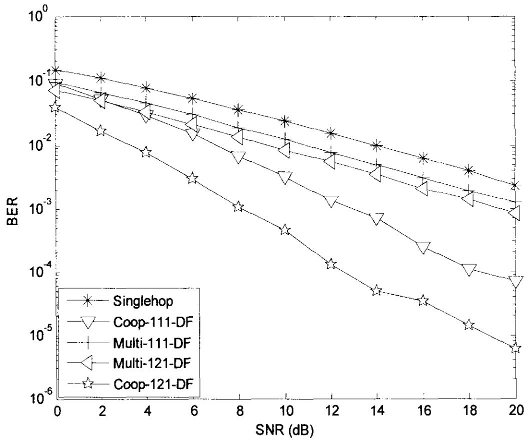

Fig. 3 BER performance of the 1-2-1 DF cooperative protocol

Fig. 3 compares the optimal performances of each protocol with the total transmit power P_T. At the target BER of 10^{-2}, the 1-2-1 DF cooperative protocol only requires about 3dB. Thus, the proposed protocol get better energy saving compared with single-hop, 1-1-1 DF cooperative protocol, 1-1-1 DF multi-hop and 1-2-1 DF multi-hop that require 13dB, 4dB, 8dB, 6dB higher energy, respectively. In addition, the proposed protocol outperforms the three protocols regardless of SNR.

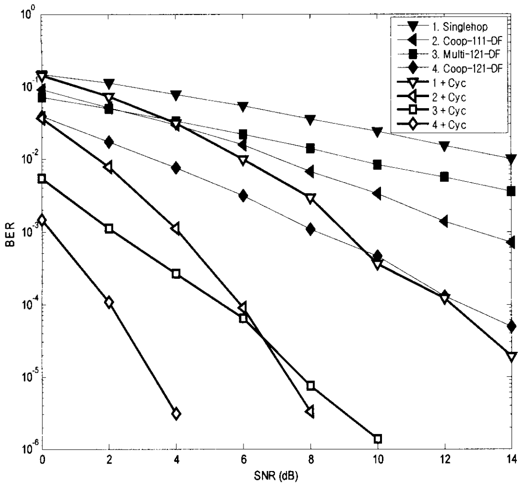

Fig. 4 BER performance of the 1-2-1 DR protocols with Cyclic code

Fig. 4 indicates the BER performance of proposed 1-2-1 DR cooperative protocol. We use the cyclic code (23,12) with the generator polynomial[8] given by $g(p) = p^{11} + p^9 + p^7 + p^6 + p^5 + p + 1$ to get the coding gain. This code can correct up to 3 bit errors. We consider four cases (single-hop, 1-1-1 DF cooperative protocol, 1-2-1 DF multi-hop, 1-2-1 DF cooperative protocol) on Fig. 4. It is obvious that the performance of the protocols with channel coding is always better than others. 1-2-1 DR cooperative protocol has the best performance regardless of SNR.

Therefore, we organize efficient cluster based WSNs using 1-2-1 cooperative protocol in Fig. 5. The transmit power P_{CH} of CHs is $k*P_S$ (k=1, 2, 3, …) because CHs in cluster have larger energy than that of SN. In Fig. 4, Single-hop presents BER performance of single-hop among SN and CH. The Singlehop-$k*P_S$ presents BER performance of whole network with single-hop applied to both SN-CH link and CH-Sink link. Coop-121-DF presents BER performance of 1-2-1 DF cooperative protocol among SN and CH.

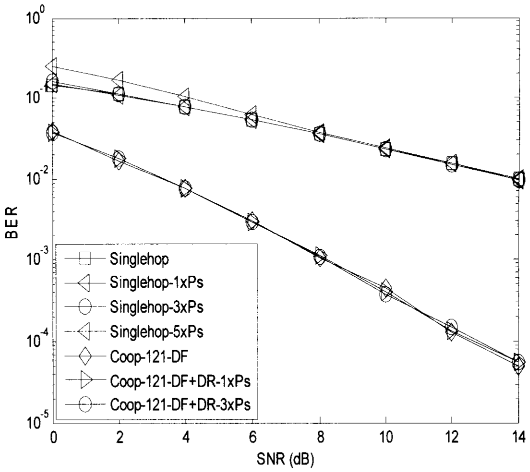

Fig. 5 BER performance of the proposed WSNs with changing CH's transmit power

Coop-121-DF+DR-$k*P_S$ in Fig. 5 presents the BER performance of whole network with 1-2-1 DF cooperative protocol applied to SN-CH link and 1-2-1 DR cooperative protocol applied to CH-Sink link. The transmit power of SN and two relays are $P_S=P_{R1}=P_{R2}=P_T/3$ and the transmit power P_{CH} of CHs is $P_{CH}=1*P_S$, $3*P_S$, $5*P_S$. For example, the transmit power of Singlehop-1xP_S is P_{CH}=PS. Here, the BER performance deteriorates due to the effect of channel in CH-Sink. However, if the SNR increase, this line is equal to the BER line of Single-hop. Thus, in Fig. 5, Singlehop-1xP_S gets the same performance with Single-hop when the transmit power P_{CH} is over $3*P_S$, while Coop-121-DF+DR get the same performance with Coop-121-DF even if P_{CH} is P_S. Therefore, the efficient communication protocol from SN to CH in cluster is most important to keep the desired performance.

Ⅳ. Conclusions

In this paper, we propose 1-2-1 cooperative protocol using two DF/DR cooperative relays. The proposed 1-2-1 DF/DR cooperative protocol improves path-loss reduction and increases diversity order 3. Moreover, the cooperative relay R_2 between S and D offers diversity order 2. Thus, the proposed 1-2-1 cooperative protocol is enables to get higher reliability and power consumption reduction than the those of conventional cooperative protocols. Finally, in terms of energy-saving and reliability, 1-2-1 cooperative protocol that is adequate and realistic will be applied to WSNs to obtain high diversity order.

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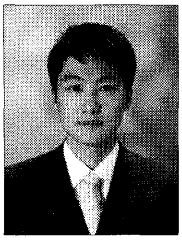

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