논문 2008-6-10

협력-순환 부호를 이용한 무선 센서 네트워크에서의 전력 소모 감소를 위한 결합기법에 관한 연구

A Combining Scheme to Reduce Power Consumption in Cooperation and Cyclic Code for Wireless Sensor Networks

공형윤**, 황윤경*, 홍성욱*

Hyung Yun Kong, Yun Kyeong Hwang*, Seong Wook Hong***

요 약 본 논문은 센서 네트워크에서 데이터의 신뢰도를 높이고, 전력 효율적인 프로토콜을 제안한다. 그러기 위하여 최대비 결합(MRC)과 순환 부호를 적용한 협력통신 프로토콜을 제안한다. 하나의 소스노드와 하나의 중계노드는 각각의 시간 슬롯에 목적지로 동일한 데이터를 전송하고, 목적지 노드는 각각의 신호를 수신함으로써 다이버시티 효과를 획득할 수 있다. 제안한 프로토콜은 순환부호를 사용함으로써 3-비트의 오류정정능력을 가지며, 많이 사용되는 콘볼루션 코드에 비하여 복호 시 낮은 복잡도를 가진다. 본 논문의 모의실험 결과를 통하여 BER이 10^{-2}일 때, 단일 홉 전송의 경우에 비하여 6dB의 전력을 절약 할 수 있다는 것을 증명하였다.

Abstract In this paper, our goal is to find a power-effective protocol that improves the accuracy of transmission in sensor networks. Therefore we propose a cooperative communication protocol based on MRC(Maximal Ratio Combining) and cyclic code. In our proposal, one sensor node assists two others to communicate with a clusterhead that can get diversity effect and MRC can improve diversity effect also. The proposed protocol with cyclic code can correct error up to 3-bit and reduce decoding complexity compared with convolutional code. Simulation results reveal proposed protocol can save the network energy up to 6dB over single-hop protocol at BER(Bit Error Rate) of 10^{-2}.

Key Words : Cooperative communication, Wireless security, Physical layer, Channel coding, Generator matrix

I. Introduction

Recent advances in wireless sensor networks have enabled the development of low-cost and multi-functional sensor nodes. Therefor sensor networks can be used for various application areas[1]. A sensor node has the capabilities to collect data and rout data back to other nodes or a high rank administrator. In traditional Wireless Sensor networks, transmission of data use single-hop and multi-hop. But they are not well suited to the unique features and application requirements of wireless sensor networks. Efficient energy utilization is a stringent design criterion for sensor networks since each sensor node must operate for several months on a single battery[2]. In addition, reliable communications over wireless channels, have a serious problem of fading due to multipath propagation. It can be mitigated using diversity effect at transmitter and receiver by deploying multiple antennas at transmitter and using combiner at receiver. The advantages of

---

** 정회원, 울산대학교 전기전자정보시스템공학부
* 학생회원, 울산대학교 전기전자정보시스템공학부
접수일자 2008.9.20, 수정완료 2008.12.5

MIMO(Multiple-Input Multiple-Output) systems have been widely acknowledged, to the extent that certain transmit diversity methods. However, sensor devices may not be able to support multiple antennas due to size and power limitation or other constraints. To overcome these restriction, a new technique, called cooperative transmission, was born which allow single-antenna devices to reap some of the benefits of MIMO system and similar diversity effect. And through using combiner at the receiver, we can get more effective diversity effect without additional deveces and power[3]-[10].

There are three kinds of combiners EGC(Equal Gain Combining), MRC and SC(Selection Combining). Depend on types of combiners, diversity effect reveal differently and we prove the best combiner is MRC. When evaluating the performance of Decode-and-Forward (DF) relaying system or repetition coding[13] on Rayleigh fading channels using Maximal Combining Ratio (MRC) combining technique[14] at the destination, we usually deal with the problem of finding the expression for pdf of a sum of independent exponential random variables. Basic method of cooperative transmission are amplify and forward, decode and forward and hybrid and forward. Amplify and forward send massage to relay and destination at the same time. At relay amplify received signal and retransmit it. And noise amplify also that degrades BER performance. Coded cooperation take same processing but at the relay, after correct received signal and retransmit it. This protocol reveal highest BER performance in three. In additional hybrid and forward compose above protocols, it has the worst performance among three protocols[6]-[8]. Decode and forward appears to be a proper choice in wireless sensor networks because it shows the lowest complexity and high performance.

Wireless channel has random behavior and error control coding is essential part. The convolutional code is widely used as FEC(Forward Error Correction) method in the most popular wireless communication systems[9]. However, it presents a fragile property in burst error and very complex. So we propose cyclic code in wireless sensor networks. The encoding and decoding of cyclic codes implemented by shift registers with very low cost and negligible hardware complexity. Therefore, it is easily to make a proposed protocol brings a considerable energy saving due to high BER performance.

The rest of the paper is organized as follows. Part 2 presents the proposed cooperative transmission protocol. Then the simulation results that compare the performance of the proposed protocol with conventional protocol in part 3. Finally, the paper is closed in part 4 with a conclusion.

II. Proposed Cooperative Transmission Protocol

We investigate a communication protocol have power saving efficiency for wireless sensor network. In single-hop protocol, sensor node sends its data directly to the clusterhead without the help of any intermediate node. In multi-hop protocol, data transmission has to pass through several partners before reaching the destination. The partners 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 which is nearest to the destination. It is shown that protocol can only extend range or save transmit power but achieves no diversity gain. However, in cooperative transmission protocol, we can get power saving and diversity efficiency also. This protocol is an extension of the multi-hop protocol where the receiver combines the data from the desired source node and all its partners instead of only from the last partner as for the multi-hop protocol. Consider a certain protocols as shown in Fig. 1. The information sent from any source node can reach its clusterhead in the following ways.

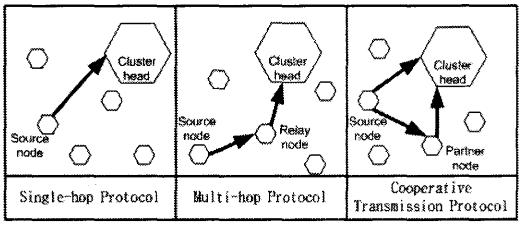


Fig. 1. The Protocols of sensor networks

To make use of cooperative transmission protocols most efficiently with low power consumption and low-complexity protocol is our final goal in this paper. We assume that each source node is equipped with an encoder and decoder of cyclic codes, a BPSK modem, a single-antenna for both reception and transmission, and a perfect carrier-frequency and carrier-phase synchronizer.

We denote the transmitting source node as S, its partner node as P and clusterhead as C. The proposed protocol consists of two time durations. In the first time duration, S encodes a K-bit input data (dK ⋯ d1) with an (N, K) cyclic code to generate a N code-chip codeword (cN ⋯ c1). This codeword is BPSK-modulated and up-converted to the carrier frequency before being sent over the channel in Fig. 2.

Specifically, if the output signal of the modulator is a[n] which takes values +1 and -1 with equal probability where n denotes nth code-chip interval, the transmitted signal corresponding to a[n] is

$$S_S(t) = \sqrt{2P_S}a[n]\cos(2\pi f_c t) \cdot P(t-nT_c) \qquad (1)$$

where fc is carrier frequency, p(t) a unit-amplitude rectangular pulse with Tc-width, Tc the chip duration, PS the average power of S.

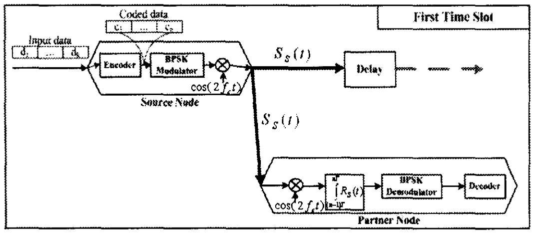


Fig. 2. The Proposed protocol - First time slot

At the same time, both P and delay block receive the faded noisy versions of SS(t) as

$$R_{SP}(t) = \sqrt{2P_S}\alpha_{SP}a[n]\cos(2\pi f_c+\Phi_{SP}(t)) \cdot P(t-nT_c)+n_{SP}(t) \qquad (2)$$

$$R_{SC}(t) = \sqrt{2P_S}\alpha_{SC}a[n]\cos(2\pi f_c+\Phi_{SC}(t)) \cdot P(t-nT_c)+n_{SC}(t) \qquad (3)$$

where α_{SP} is the fading amplitude caused by the channel between S and P, C. $\Phi_{SP}(t)$, $\Phi_{SC}(t)$ capture the fading phase and propagation delay. nSP(t), nSC(t) are also Gaussian random variable with zero-mean and the same variance. Exact phase and frequency synchronization have also been assumed.

Now, the signal processing at P works as follows. First, the received signal RSP(t) is down-converted and integrated over a code-chip duration. The integrator output is then sampled every TC, resulting in the following signal at the time instant nTC. And nSP[n] is same as nSP(t).

$$R_{SP}[n] = \sqrt{2P_S}\alpha_{SP}[n]a[n]+n_{SP}[n] \qquad (4)$$

Second, delay block stores N values of RSC[n], n= 1,⋯,N, in the buffer. However, P has to perform much more signal processing. It continues BPSK-demodulating partner node to generate the estimated code-chip of dn as

$$\overline{d_n}=\begin{cases}1, & R_{SP}[n]\geq 0\\ 0, & R_{SP}[n]<0\end{cases} \qquad (5)$$

Then N code-chips are fed to the cyclic decoder. Decoded data K bits are considered as input data of the partners encoder.

In the second phase, the partner sends the estimated data of S to the destination. Generating the transmitted signal at P is completely similar to that at S. That means data is passed through the encoder in Fig. 3.

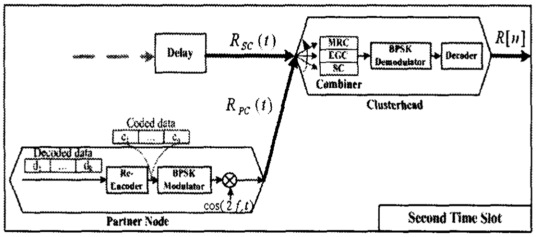


Fig. 3. The Proposed protocol - Second time slot

Therefore, P forwards the signal in (6) to the clusterhead as its turn is reached.

$$S_P(t)=\sqrt{2P_P}a[n]\cos(2\pi f_ct)\cdot P(t-nT_c) \qquad (6)$$

The above signal is also affected by the channel fading and AWGN at C.

$$R_{PC}(t)=\sqrt{2P_S}\alpha_{PC}[n]a[n]\cos(2\pi f_ct+\Phi_{PC}(t)) \cdot P(t-nT_c)+n_{PC}(t) \qquad (7)$$

The received signal RPC(t) and expression (3) are down-converted and integrated over a code-chip duration. The integrator output is then sampled every TC, resulting in the following signal at the time instant nTC. Similarly, as in the first phase, we obtain the signal at the output of the sampler of C as

$$R_{SC}[n]=\sqrt{2P_S}\alpha_{SC}[n]a[n]+n_{SC}[n] \qquad (8)$$

$$R_{PC}[n]=\sqrt{2P_P}\alpha_{PC}[n]a[n]+n_{PC}[n] \qquad (9)$$

Now, the clusterhead combines the signal received from delay bolck given in (8) which is available in its buffer, with that from its partner in (9) to detect each original chip-code. It requires the amplitude of path gains, α_{SC}, α_{PC} between S, P and C are Rayleigh distributed($|\alpha_{SC}|^2$, $|\alpha_{PC}|^2$ is exponential distributed random variable with mean λ_{SC}, λ_{PC}).

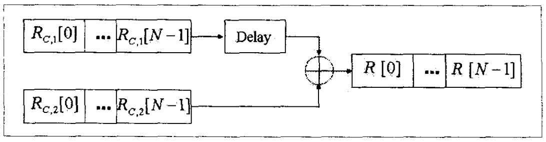


Fig. 4. Combining technique at Clusterhead

For combining two signals from P and S we use combiner. We compare different combiners to find different effects.

1) Case of EGC:

$$R[n]=sign\left(Real\left(\frac{\alpha^*_{SC}[n]}{|\alpha_{SC}[n]|}R_{SC}[n]+\frac{\alpha^*_{PC}[n]}{|\alpha_{PC}[n]|}R_{PC}[n]\right)\right) \qquad (10)$$

2) Case of MRC:

$$R[n]=sign\left(Real\left(\alpha^*_{SC}[n]R_{SC}[n]+\alpha^*_{PC}[n]R_{PC}[n]\right)\right) \qquad (11)$$

3) Case of SC:

If $|R_{SC}[n]|\geq|R_{PC}[n]|$

$$R[n]=sign\left(Real\left(\alpha^*_{SC}[n]R_{SC}[n]\right)\right)$$

else

$$R[n]=sign\left(Real\left(\alpha^*_{PC}[n]R_{PC}[n]\right)\right) \qquad (12)$$

Then N code-chips (R[n], n=N,...,1)are packed into a block and fed to the decoder to restore the transmitted data. The clusterhead detects data using combiner and get diversity effect.

Ⅲ. Simulation Result

Assuming that the channels between sensor nodes are independent. This is possible since the sensor node's antennas are relatively far apart from each other. Moreover, all channels experience fast and frequency-flat Rayleigh fading plus AWGN. They are constant during one chip period but change independently to the next. All protocols are associated with the (23,12) cyclic Golay code of the generator polynomial $g(X) = X_{11} + X_9 + X_7 + X_5 + X + 1$. This code can correct up to 3 errors[9].

For a fair comparison, it is essential that the total consumed energy of the cooperative system does not exceed that of corresponding single-hop protocol. This is a strict and conservative constraint. Applying this energy constraint requires $P_S = P_P = P_T/2$ where P_T is total power of the system which is also the transmit power of sensor node in case of single-hop communications.

To capture the effect of path loss on overall performance, we use $\lambda_{SP}^2 = (d_{SD}/d_{SP})^\beta$, $\lambda_{PC}^2 = (d_{SD}/d_{PC})^\beta$. For suburban environment, we have β=3 and only this case is considered in the simulation. In addition, we assume the partner is located on a line between S and C, and the direct path length S-C is normalized to 1.

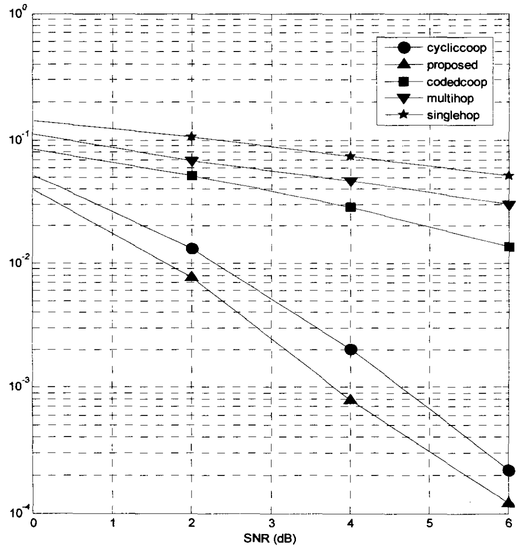


Fig. 5. The Performance of Protocols.

The proposed cooperative transmission protocol always outperforms the single-hop protocol, multi-hop protocol and conventional coded cooperation protocol. Cyclic code attached in conventional coded cooperation and compare with proposed protocol. Coding gain is 4dB only near by BER of 10-2. The proposed protocol using MRC(d=0.2) perform better than conventional coded cooperation protocol with cyclic code.

Fig. 4 compares the optimal BER performances of protocols via SNR. At the target BER of 10-2, the proposed protocol can save the system energy above 4dB and 6dB in comparison to the multi-hop and single-hop cases, respectively. In addition, energy saving keeps increasing proportional 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.

Fig. 5. compare the three combiners to observe diversity effect of different combiner. The protocols are designed according to above numerical formula (10)-(12). We compare three most popular combining techniques and found that MRC maximize the performance over EGC and SC at Fig. 5. SC and EGC have similar performance. We compare with d=0.2 and d=0.4 which are distance between S and P and at d=0.4 performance of the system is better.

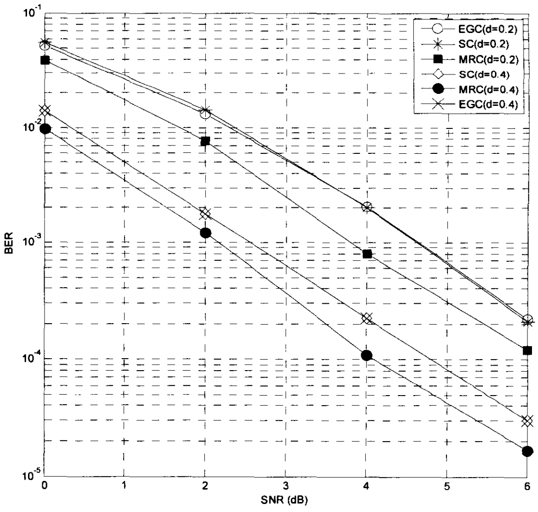


Fig. 6. The Performance of Combiners (d=0.2, 0.4).

Ⅳ. Conclusion

The proposed protocol increases a significant energy efficiency without requiring additional implementation complexity for sensor networks. This was confirmed by simulation results under the fast and flat Rayleigh fading plus Gaussian noise. The MRC based proposed protocol improves the performance of about more than 6dB over the single-hop protocol. Energy saving that the cooperation achieved is equivalent to prolonging sensor network lifetime and better satisfying the critical design condition of wireless sensor networks. Therefore, the cooperation scheme with cyclic coding is feasible technique for the future wireless sensor networks.

Reference

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks”, IEEE Communications Magazine, Vol. 40, Issue 8, pp. 102-114, Aug. 2002.

[2] E. Shih et al., “Physical Layer Driven Protocol and Algorithm Design for Energy-Efficient Wireless Sensor Networks”, Proc. ACM MobiCom '01, pp. 272 - 86, Rome, Italy, July 2001.

[3] A. Nosratinia, A. Hedayat, and T. E. Hunter, “Cooperative Communication in Wireless Networks”, IEEE Communications Magazine, Vol. 42, Issue 10, pp. 74-80, Oct. 2004.

[4] E. Zimmermann, P. Herhold, and G. Fettweis, “On the Performance of Cooperative Relaying in Wireless Networks”, European Trans. on Telecommunications, Vol. 16, No. 1, Jan-Feb 2005.

[5] J.N. Laneman, D.N.C. Tse, and G.W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior”, IEEE Trans. Inform. Theory, Vol. 50, Issue 12, pp. 3062 - 3080, Dec. 2004.

[6] E.G. Larsson and Y. Cao, “Collaborative transmit diversity with adaptive radio resource and power allocation”, Communications Letters, IEEE, Vol. 9, Issue 6, pp. 511 - 513, June 2005.

[7] A. Sendonaris, E. Erkip, and B. Aazhang, “User cooperation diversity. Part I-II”, IEEE Trans on Communications, Vol. 51, Issue 11, pp. 1927-1948, Nov. 2003.

[8] X. Li, “Energy efficient wireless sensor networks with transmission diversity”, Electronics Letters, Vol. 39, Issue 24, pp. 1753 - 1755, 27 Nov. 2003.

[9] H. Ochiai, P. Mitran, and V. Tarokh, “Design and analysis of collaborative diversity protocols for wireless sensor networks”, VTC2004-Fall, Vol. 7, pp. 4645-4649, 26-29 Sept. 2004.

[10] J.G. Proakis, “Digital communications”, Fourth Edition, pp.356-370, McGraw-Hill, 2001.

※ Acknowledgement : 본 연구는 산업자원부와 한국산업기술재단의 지역혁신인력양성사업으로 수행된 연구 결과임

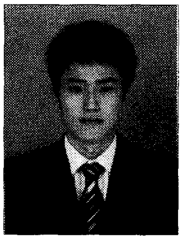
저자 소개

공 형 윤(정회원)

- 1989년 2월 : New York Institute of Technology(미국) 전자공학과 학사
- 1991년 2월 : Polytechnic University (미국) 전자공학과 석사
- 1996년 2월 : Polytechnic University (미국) 전자공학과 박사
- 1996년~1996년 : LG전자 PCS 팀장
- 1996년~1998년 : LG전자 회장실 전략 사업단
- 1998년~현재 : 울산대학교 전기전자정보시스템공학부 교수

<주관심분야> 모듈레이션, 채널 부호화, 검파 및 추정 기술, 협력통신, 센서 네트워크

홍 성 욱(학생회원)



- 2008년 2월 : 울산대학교 전기전자정보시스템공학부 학사
- 2008년 3월 : 울산대학교 전기전자정보시스템 공학과 석사과정

<주관심분야> 변복조 기술, 부호화 기술, 무선센서네트워크, 협력통신, MIMO

황 윤 경(학생회원)

- 2006년 2월 : 울산대학교 전기전자정보시스템공학부 학사
- 2008년 2월 : 울산대학교 전기전자정보시스템 공학과 석사

<주관심분야> 고속 변복조 시스템, 채널 코딩, 협력 통신, Wireless Sensor Network