

Cooperative Communication in Clustered Wireless Sensor Network Based on LDPC Codes

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Abstract. In this paper, considering a clustered wireless sensor network, we propose a cooperative transmission scheme based on virtual multiple antennas combining with advanced channel coding (such as low density parity check codes), and give the system performance under different conditions through simulation. The whole transmission can be divided into two stages: at the first stage, cluster head broadcasts the information and other sensors listen, which we call it intracluster broadcasting phase, at the second stage, sensors that can correctly decode the received information participate in the cooperative transmission, which we call it intercluster transmission phase. Then we minimize the overall energy consumption by adjusting the power allocation between these two transmission phase. Compared with the research so far, we apply advanced channel coding at each sensor node, which makes the system performance much better.

Introduction

In recent years, wireless sensor networks (WSN) are widely used in environmental monitoring, healthcare assistance, military applications and so on, which gain a lot of attention of researchers. Wireless sensor networks are typically energy constrained networks, sensor nodes are powered by batteries which are difficult to replace. Consequently, minimizing the energy consumption and extending the lifetime of whole network are very important issues for wireless sensor networks[1,2].

Researchers in paper [3] presented an efficient data gathering scheme that guarantees the Quality of Service, paper [4] introduced a cross-layer operation model that can improve the energy consumption and system throughput of IEEE 802.15.4 Mobile WSNs. Zhou Zhou etc. proposed cooperative communication scheme for a clustered wireless sensor network where sensors within each cluster relay data packets to nearby clusters[5], but they didn't consider the more powerful error correcting codes, such as low-density parity check codes (LDPC). Based on the research above, we propose a cooperative transmission scheme for clustered wireless sensor network based on LDPC codes with different modulation and coding schemes.

The rest of this paper is organized as follows. In Section II, we present the system model and. How to minimize the total energy is explained in Section III. In Section IV, we get numerical results through simulations. Finally, some conclusions are drawn.

System Model

The clustered wireless sensor network model we considered is shown in fig.1, the whole information transmission process can be divided into two stages. At the first stage, cluster head broadcasts the information and other sensors listen, which we call it intracluster broadcasting phase, at the second stage, sensors that can correctly decode the received information participate in the cooperative transmission, which we call it intercluster transmission phase. And at each node, Low-density parity-check codes are employed as the forward error correcting method.

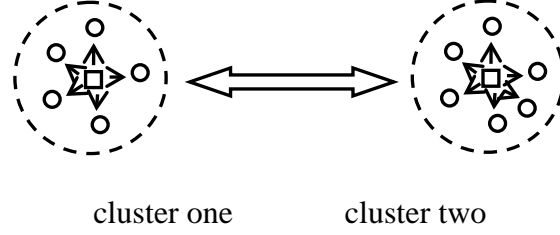


Fig.1 Clustered wireless sensor network

Performance analysis

Firstly, we analyze the performance of intracuster communication. Without generality, we assume that the cluster head (the source node) locates at the center of the cluster, and there are N normal sensor nodes (the receiving node) uniformly distributed in a circle with radius R_1 around the cluster head. Let r denote the distance between the source node and a receiving node, with the probability density function as follows

$$f(r) = \frac{2r}{R_1^2} \quad 0 < r \leq R_1 \quad (1)$$

Under the assumption of independent Rayleigh fading, the channel coefficients are modeled as independent and identically distributed (i.i.d.) complex circular Gaussian random variables with zero mean and unit variance. The average received SNR $\bar{\gamma}_1$ at one node can be written as

$$\bar{\gamma}_1 = \frac{E_{t1}}{N_0 r^2} \quad (2)$$

Where E_{t1} denotes the average transmission energy per symbol, N_0 is the one-side AWGN spectral density at the receiver, The instantaneous received SNR γ_1 has an exponential distribution as

$$f(\gamma_1) = \frac{1}{\bar{\gamma}_1} e^{-\frac{\gamma_1}{\bar{\gamma}_1}} \quad (3)$$

If the instantaneous value of γ_1 is known, we can take the channel as an AWGN channel. For LDPC codes, an approximate expression for PER is provided as follows [6]:

$$\text{PER}_n(\gamma_1) = \begin{cases} 1, & \text{if } 0 < \gamma_1 < \gamma_{cf} \\ \left(\frac{1}{1 + \exp\{c_n(\gamma_1 - b_n)\}} \right)^{a_n}, & \text{if } \gamma_1 \geq \gamma_{cf} \end{cases}, \quad (4)$$

where n depends on the modulation and coding (MCS) schemes, γ_{cf} is the SNR cut-off value indicating that no information will be transmitted when the instantaneous SNR falls below it, a_n , b_n , c_n and γ_{cf} are parameters obtained by fitting (4) to the simulation results [7].

Given an average SNR $\bar{\gamma}_1$, the PER averaged over Rayleigh fading is given by

$$\overline{\text{PER}}_1(\bar{\gamma}_1) = \int_0^\infty \text{PER}_n(\gamma_1) f(\gamma_1) d\gamma_1 \quad (5)$$

Since $\overline{\text{PER}}_1(\bar{\gamma}_1)$ is the function of two random variables $\bar{\gamma}_1$ and E_{t1} , we rewrite it as $\overline{\text{PER}}_1(E_{t1}, r)$, averaging $\overline{\text{PER}}_1(E_{t1}, r)$ over the r leads to

$$\overline{\text{PER}}_1(E_{t1}) = \int_0^{R_1} \overline{\text{PER}}_1(E_{t1}, r) \frac{2r}{R_1^2} dr \quad (6)$$

Assuming that there are M sensor nodes correctly decode the received packet. The probability is given by

$$P(M) = \binom{N}{M} [1 - \overline{PER}_1(E_{t1})]^M [\overline{PER}_1(E_{t1})]^{N-M} \quad (7)$$

The mean value of M is thus

$$M_E = E(M) = N[1 - \overline{PER}_1(E_{t1})] \quad (8)$$

At the second transmission phase, information will be transmitted between the transmitting and receiving clusters, which we call i intercluster Cooperative Transmission.

In cluster one, the source node together with another M nodes (relay nodes) will jointly transmit packets using the distributed space-time block coding (STBC), so the total number of transmission nodes is $M_0 = M + 1$. Let D denote the distance between two clusters, and D is much larger than the intracuster distance, so we can approximate the transmission distances between all the transmitting nodes and the receiving node as D. then the average received SNR $\bar{\gamma}_2$ corresponding to each relay node is

$$\bar{\gamma}_2 = \frac{E_{t2}}{N_0 D^2} \quad (9)$$

Where E_{t2} is the transmission energy per symbol per node. The effective received SNR γ_2 conditional on channel realizations is

$$\gamma_2 = \left(\sum_{i=1}^{M_0} |h_i|^2 \right) \bar{\gamma}_2 \quad (10)$$

Where h_i is the channel coefficient between the i th transmitting node and the receiving cluster head. We assume that the h_i 's are independent and identically distributed Rayleigh fading distribution. And then γ_2 is of a central chi-square distribution with $2M_0$ degrees of freedom

$$f(\gamma_2) = \frac{1}{\Gamma(M_0) \bar{\gamma}_2^{M_0}} \gamma_2^{M_0-1} e^{-\frac{\gamma_2}{\bar{\gamma}_2}} \quad (11)$$

The average PER with M_0 transmitting nodes is then

$$\overline{PER}_2(\bar{\gamma}_2, M_0) = \int_0^{\infty} PER(\gamma_2) f(\gamma_2) d\gamma_2 \quad (12)$$

Since $\overline{PER}_2(\bar{\gamma}_2, M_0)$ is a function of E_{t2} and M_0 , we can rewrite it as $\overline{PER}_2(E_{t2}, M_0)$. Combining (7), (13) and $M_0 = M + 1$, the end-to-end average PER is

$$\begin{aligned} \overline{PER}(E_{t1}, E_{t2}) &= \sum_{M=0}^N P(M) \overline{PER}_2(E_{t2}, M+1) \\ &= \sum_{M=0}^N \binom{N}{M} [1 - \overline{PER}_1(E_{t1})]^M \times [\overline{PER}_1(E_{t1})]^{N-M} \overline{PER}_2(E_{t2}, M+1) \end{aligned} \quad (13)$$

For simplicity, we didn't consider the circuit energy consumption, then the average total energy consumption \bar{E}_{packet} for a packet is

$$\bar{E}_{packet} = \frac{1}{b} L_b \times \{E_{t1} + [N(1 - \overline{PER}_1(E_{t1})) + 1] \times E_{t2}\} \quad (14)$$

E_{t1} is the transmit energy of source node in the first phase, E_{t2} is the transmit energy of source node in the second phase, b is the number of bits in each symbol, L_b is the number of bits in a packet.

To minimize the overall energy consumption for a packet under a certain PER requirement, the optimization problem over the transmission energy (E_{t1} and E_{t2}) can be illustrated as [5]

$$\min_{E_{t1}, E_{t2}} \bar{E}_{packet} = \frac{1}{b} L_b \times \{E_{t1} + [N(1 - \overline{PER}_1(E_{t1})) + 1] \times E_{t2}\}$$

Subject to $0 \leq E_{t1} \leq E_{max}$

$$\begin{aligned} 0 \leq E_{t2} \leq E_{\max} \\ \overline{PER}(E_{t1}, E_{t2}) \leq \overline{PER}_0 \end{aligned} \quad (15)$$

Where E_{\max} is the maximum transmitting energy per symbol allowed at each node, and \overline{PER}_0 is the target PER specified by the users.

There are many parameters that can be adjusted to optimize the energy consumption, such as the number of nodes N in the cluster, cluster size $R1$, and cluster distance D . But in our research, we focus on the coding rate, modulation and coding schemes, which will determine a_n , b_n , c_n and γ_{cf} in the PER formula.

Rate-compatible LDPC codes

LDPC codes are block codes that exhibit near Shannon limit performance. They were first introduced by Gallager in his thesis in 1960's [8] and rediscovered by D. J. C. Mackay after the debut of Turbo codes [9]. LDPC codes are linear block codes, which are defined by very sparse parity-check matrices H having dimension $m \times n$. LDPC codes are usually represented by bipartite graphs, in which one set of nodes called the variable nodes, corresponds to the information bits of the codeword and the other set of nodes called the check nodes, corresponds to the set of parity-check constraints which define the codes. An LDPC code is called regular if every variable node participates in d_v check nodes and every check node involves d_c variable nodes, otherwise it is called irregular. For an irregular LDPC code, the degrees of each set of nodes are chosen according to some distribution..

RC-LDPC codes are a family of nested codes with wide range code rates generated by a low-rate LDPC code, which is the so-called mother code. A lot of work has been done to find the optimum puncturing and extending pattern, but random puncturing has been adopted in most applications. The problem of random puncturing is that the receiver cannot get the puncturing pattern easily. Therefore, it is difficult to put random puncturing into practice. Here, we proposed a simple puncturing method that is easy to implement and can get as good performance as random puncturing.

We construct the mother code by using the progressive edge growth (PEG) method [10], which has been proven to be able to produce the best LDPC codes with moderate code length and can generate a weight-increasing parity-check (WIPC) matrix. We employ LDPC codes with rate 1/2 (1008, 504) in our simulations. The variable node degree distribution of irregular LDPC codes is as follows

$$\lambda(x) = \sum_i \lambda_i x^i = 0.47532x^2 + 0.27953x^3 + 0.03486x^4 + 0.10889x^5 + 0.10138x^{15}. \quad (16)$$

Then, the bits with degree 2 are all located in the right of the parity check matrix, corresponding to the parity check bits. When constructing RC-LDPC codes, puncturing those bits with lower degree can have less impact on the configuration of the mother code. So, for a given rate, we implement a continuous puncturing from those bits with the lowest degree.

Numerical result

In this section, we compare the performance of the proposed system under different modulation and coding schemes. The parameters are set as follows: $R_1 = 20m$, $D = 200m$, $\overline{PER}_0 = 0.01$, $N=10$, $N_0 = 10^{-10}$ W/Hz, the parameters a_n , b_n , c_n and γ_{pn} for PER calculation are shown in table 1 [7].

Through computer simulation, we get the Overall energy consumption per packet versus E_{t1} under different MCS, as we can see from fig.2, the optimal E_{t1} for different MCSs are different, but very close.

Table 1. Parameters of MCSs

	MCS1	MCS2	MCS3	MCS4
Modulation	BPSK	QPSK	QPSK	16QAM
Coding rate	1/2	1/2	3/4	3/4
R_n (bits/sym)	0.50	1.00	1.50	3.00
a_n	2.0711	2.4654	1.3988	1.2032
b_n	-1.9453	1.1845	4.3105	10.334
c_n	3.9263	3.0263	2.9004	3.0533
γ_{cf} (dB)	-3.3017	-0.63305	2.61	8.7682

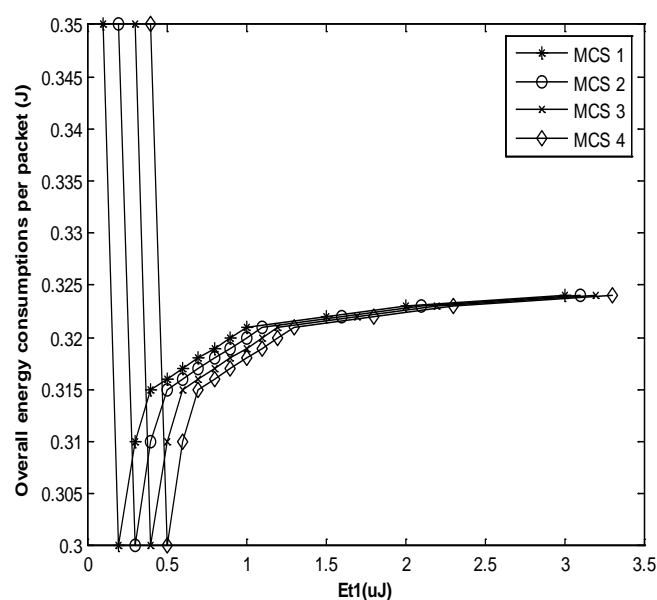


Fig.2 Overall energy consumption per packet versus E_{t1} under different MCS

Conclusion

In this paper, we proposed a framework of cooperative transmission schemes in clustered wireless sensor network, the powerful error correcting code LDPC codes are employed by each sensor nodes, through simulation, we give the Overall energy consumption per packet versus E_{t1} under different MCS.

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