Joint Selection for Cooperative Spectrum Sensing in Wireless Sensor Networks

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***Abstract*— A joint selected strategy is proposed for wireless sensor networks to address the energy consumption problem in this letter. The proposed strategy saves energy by selecting the sensor and modulation constellation size. Results from simulations show that the proposed strategy obtains significant energy reduction compared with the existing strategy under the same environment.**

***Index Terms*— Joint, wireless sensor networks (WSNs), sensing node, constellation size, energy consumption.**

I. Introduction

Cooperative spectrum sensing technique has been proved as a good candidate for improving the detection sensitivity in wireless sensor networks (WSNs) [1]–[2]. Many studies in this area have been trying to exploit the full advantages of using cooperative spectrum sensing with other technologies [3]–[5]. Among the technologies, sensor selection is one of the hot issues. In [3], an energy-efficient cooperative spectrum sensing scheme based on sensing node selection is proposed, and the energy consumption efficiency is inspected by considering detection probability and false alarm probability constraints.

In this letter, based on sensor selection, a joint selected strategy is proposed to reduce the energy consumption. In the proposed strategy, the energy efficiency is achieved by jointly selecting the sensor and modulation constellation size. To the best of our knowledge, we make the first attempt at proposing joint selected strategy and such strategy is quite novel.

II. Problem Setup and Analysis

A WSN composed of one primary user, one fusion center, and M sensors where each sensor has L antennas is assumed. One antenna for sending and multiple antennas for sensing are executed. According to [3], the total energy consumption of the WSN including the sensing energy and sending energy is defined as

$$E_{tot} = \sum\nolimits_{i=1}^{M} \rho_i \left[\sum\nolimits_{l=1}^{L} E_{si,l} + E_{ti} \right] \tag{1}$$

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where ρ_i is 1 or 0 meaning that a sensor participates in spectrum sensing or not, respectively. $E_{si,l}$ and E_{ti} are energy consumed by lth antenna of ith sensor in sensing stage and energy consumed for sending from ith sensor, respectively. E_{ti} can be calculated by using equation as shown below

$$E_{ti} = E_{t-el} + e_{amp}(d_i^2) \tag{2}$$

where E_{t-el} is the sensor circuit energy for sending; e_{amp} is the required energy for satisfying sensitivity level of the receiver; d_i is the transmission distance.

Considering the system performance, the probability in the fusion center should satisfy global detection constraints: $P_d \geq \beta$ and $P_f \leq \alpha$ where P_d is the sum of the local detection probability of each sensor P_{di} and P_f is the sum of the local false alarm probability of each sensor P_{fi}; α and β are desired parameters, respectively. P_{fi} and P_{di} are given as

$$P_{fi} = Q(\left(\frac{T}{L\sigma_\omega^2} - 1 \right) \sqrt{N}) \tag{3}$$

$$P_{di} = Q(\left(\frac{T}{L\sigma_\omega^2} - \gamma_{i,EGC} - 1 \right) \sqrt{\frac{N}{2\gamma_{i,EGC} + 1}}) \tag{4}$$

where T is the decision threshold in energy detector; N is the number of samples for a valid decision; and signal to noise ratio (SNR) $\gamma_{i,EGC}$ is given as

$$\gamma_{i,EGC} = \frac{\sum_{l=1}^{L} \left| h_{i,l} \right|^2 \cdot \ P_t}{L\sigma_\omega^2}. \tag{5}$$

In (5), $h_{i,l}$ is the channel gain between lth antenna of ith sensor and primary user; P_t is the transmitter power; and independent Gaussian distribution noise samples with average of zero and variance of σ_ω^2 are assumed.

For a data network, the traffic is usually bursty and the communication is happed on a packet-by-packet basis. Under such case, sensor spends less time in the active mode when higher modulation constellation is used for the given bits; therefore more time will be assigned to the sleeping mode. Thus the total energy is reduced due to the reduced ratio of active mode. On the other hand, higher modulation constellation size requires higher transmitting power. Therefore, increasing the active time and decreasing the active time is a tradeoff; and the active time is the key parameter to optimize. Since the active time corresponds to the constellation size b (bit per symbol), the energy can be reduced by selecting the optimal constellation size. Concerning the total energy consumption, if the participating sensor and the constellation size are jointly selected, the total energy consumption can be further reduced.

When constellation size is considered, circuit energy for sending is written as E_{t-el}/b; and $e_{amp}(d_i^2)$ can be written by utilizing the link budget relationship as show below

$$e_{amp}(d_i^2) = (1+\alpha)\frac{2^{b_i}-1}{2^{b_i}} \cdot \frac{2}{3} \cdot (\frac{p_b}{4})^{-1} \cdot N_0 C d_i^2 \quad (6)$$

where $\alpha = \xi/\eta - 1$ with ξ is the peak-to-average ratio and η is the drain efficiency of the RF power amplifiers; and C is constant value which is equal to $(4\pi)^2 \cdot M_l \cdot N_f$ where M_l is the link margin compensating the hardware process variations and N_f is receiver noise; p_b is bit error ratio with the value of 10^{-3}; N_0 is the thermal noise.

Fully considering the preceding analysis, the total energy consumption of the proposed strategy can be written as

$$E_{tot-j} = \sum_{i=1}^{M} \rho_i \Big[L E_s + (1+\alpha)\frac{2^{b_i}-1}{2^{b_i}} \cdot \frac{2}{3} \cdot (\frac{p_b}{4})^{-1} \cdot N_0 C d_i^2 + \frac{E_{t-el}}{b_i} \Big] \quad (7)$$

where E_s is the total energy consumption of each sensor when equal energy consumption for each antenna is assumed. In the square bracket of (7), the second term is monotonically increasing over the integer number b_i whereas the third term is monotonically decreasing over b_i. Thus, there is an optimal value for b_i which minimizes the total energy consumption. Brute-force search is used to find the optimal b_i. The minimization of E_{tot-j} can be expressed as

$$\begin{aligned} \min_{\rho_i, b} \quad & \sum_{i=1}^{M} \rho_i \Big[L E_s + (1+\alpha)\frac{2^{b_i}-1}{2^{b_i}} \cdot \frac{2}{3} \cdot (\frac{p_b}{4})^{-1} \cdot N_0 C d_i^2 + \frac{E_{t-el}}{b_i} \Big] \\ s.t \quad & b_i \geq 1, \ i=1, 2, ..., n \\ & n \text{ is a positive integer} \\ & 1 - \prod_{i=1}^{M} (1 - \rho_i P_{f_i}) \leq \alpha \\ & 1 - \prod_{i=1}^{M} (1 - \rho_i P_{d_i}) \geq \beta \\ & \rho_i \in [0, 1]. \end{aligned} \quad (8)$$

where ρ_i is a discrete parameter with values of 0 or 1. Note that in single sensor selected strategy, the modulation constellation size is fixed by setting b_i as 1 so that binary phase shift keying (BPSK) modulation is executed.

III. Performance Evaluation

In order to evaluate the energy consumption performance of the proposed strategy, the simulation results of energy consumption under the proposed joint selected and the existing single sensor selected schemes are presented in this section. The system parameters are equivalent to those in [3]. The parameter of simulation in the detection threshold is set on $T = 3\sigma_\omega^2$, when the number of sensors is increased from 5 to 50. Two antennas are embedded in each sensor. It is assumed that the lower limit of detection probability β and upper limit of false alarm probability α are 0.95 and 0.05, respectively. The simulation is executed in 100×100 square meter environment. The optimal constellation size for different transmission distances are listed in Table I.

TABLE I
Optimized Modulation Constellation Size

d (m)	1	5	10	20	50	100
b	10	6	5	3	1	1

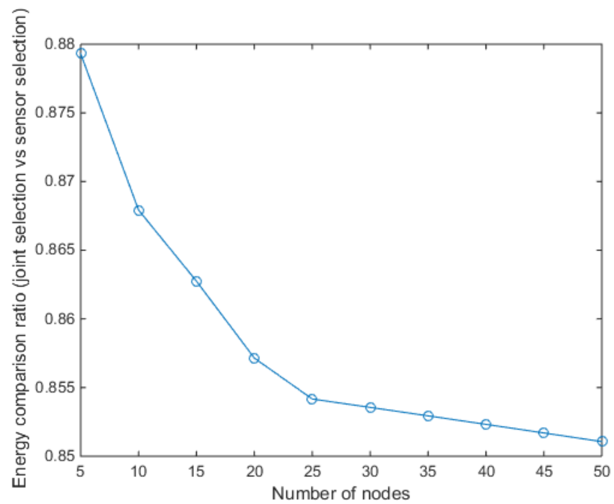

Fig. 1. Ratio of energy comparison versus number of nodes.

For each transmission distance, the optimal constellation size can be selected to reduce the energy consumption. Fig.1 shows the energy comparison ratio versus number of sensors between the proposed joint selected strategy and the existing single sensor selected strategy. According to Fig. 1, the proposed strategy is preferable since the total energy consumption is further reduced due to the constellation size selection.

IV. Conclusion

This letter proposed a novel strategy that reduces the energy consumption by selecting the sensor node and modulation constellation size in cooperative spectrum sensing based WSNs. Simulation results revealed that the achieved energy reduction in the proposed joint selection is significant when compared with the existing scheme.

References

[1] A. Ghasemi and E. S. Sousa, "Spectrum sensing in cognitive radio networks: Requirements, challenges and design trade-offs," *IEEE Commun. Mag.*, vol. 46, no. 4, pp. 32–39, Apr. 2008.

[2] T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," *IEEE Commun. Survey Tuts.*, vol. 11, no. 1, pp. 116–130, 1st Quart., 2009.

[3] S. H. Hojjati, A. Ebrahimzadeh, M. Najimi, and A. Reihanian,"Sensor selection for cooperative spectrum sensing in multiantenna sensor networks based on convex optimization and genetic algorithm," *IEEE Sensors J.*, vol. 16, no. 10, pp. 3486–3487, May 2016.

[4] Y. Peng and J. Choi, "A new cooperative MIMO scheme based on SM for energy-efficiency improvement in wireless sensor network," *Sci. World J.*, vol. 2014, Feb. 2014, Art. no. 975054.

[5] Y. Peng and C.-H. Youn, "Lifetime and energy optimization in multi-hop wireless sensor networks with spatial modulation based cooperative MIMO," *IEEJ Trans. Elect. Electron. Eng.*, vol. 10, no. 6, pp. 731–732, 2015.