Energy Allocation Algorithm for Wireless Sensor Networks Based on Binary Information

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Abstract: Wireless sensor networks, while bringing convenience to people, also facing the enormous challenges of energy issues. Each sensor node battery is limited by the size, the battery storage energy is limited and the battery is not easy to replace, so optimizing the system energy allocation is an important method to extend the life of the wireless sensor network. This paper proposes an optimal energy allocation algorithm for binary data sensing wireless sensor networks from the perspective of information rate distortion. By redesigning the optimization problem and weighting the observation accuracy, a heuristic energy allocation algorithm based on brute force search is proposed to obtain the most the energy distribution ratio was optimized, and compared with the uniform energy allocation algorithm and the heuristic energy allocation algorithm, and then the application scenarios and deficiencies of the method were discussed.

1. Introduction

Wireless sensor networks have recently received extensive attention and numerous applications, the wireless sensor network is composed of a large number of tiny sensor nodes. The sensor nodes have the functions of information collection, information processing and communication. Sensor nodes can be embedded in the corresponding devices or directly distributed in the monitoring environment. In sensor networks, each sensor node is equipped with a battery and the power is usually scarce owing to the limit battery size. Hence, the power allocation and scheduling [1-3] in sensor networks become extremely important. An optimization framework for joint source coding, routing and resource allocation was presented in sensor networks [4-6]. The distortion and power were weighted by two vectors in the optimization problem to achieve the goal of balancing the tradeoff between them. The optimization problem was solved efficiently in the dual domain. Optimal power allocation for Gaussian sensor network with distortion constraints was considered in [7], where both time division multiple access and non-orthogonal multiple access schemes are assumed in transmission phases of sensors.

We consider the power allocation in Additive White Gaussian Noise (AWGN) channel [8] for binary information sensing network from rate-distortion perspective in order to achieve optimum distortion under total power constraints. The problem is formulated in the convex optimization framework and is solved using Karush-Kuhn-Tucker (KKT) conditions. Computer simulations are performed to show the advantage of our proposed power allocation (PA) scheme.

In this paper, a power allocation scheme is proposed to minimize the distortion with a fixed total transmission power in the context of binary information sensing network. In the first phase of the paper describes the problem and some fundamental papers, followed by system model and the proposed PA algorithms in the second phase of the paper. In the third phase of the paper, the numerical results are presented. Finally, the end of the paper is devoted to conclude the discussion.

2. System Model

In the binary sensing network which is illustrated in Figure 1, a group of sensors is distributed in a specific area to observe a binary sensing object. There exists a leader, which is often called cluster head, in this group to collect the position of each sensor. The leader is in charge of calculating the observation accuracy of each sensor based on their position [9] and determining the power ratio of each sensor. The leader then broadcasts the power ration to each sensor. Meanwhile, we simply suppose that the power ratio is correctly received by each sensor.

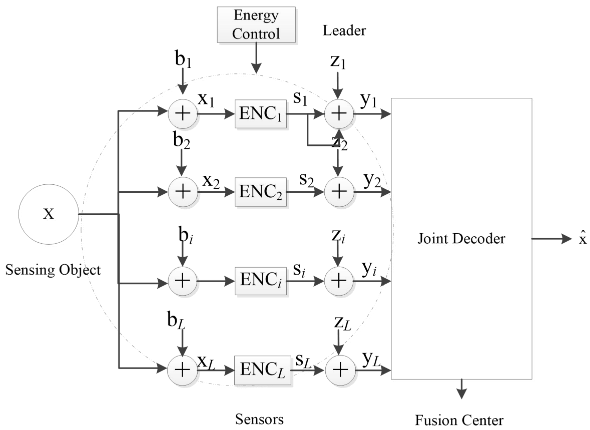

Figure 1: System model of binary information sensing network with power allocation.

After this initialization stage, each sensor encodes its observation x_i using the concatenated convolutional codes [10]. The coded sequences are then modulated by binary phase shift keying and transmitted to the fusion center over an AWGN channel noise at the receiver side is normalized1.

The problem is to determine the optimal power ratio at the leader node with fixed total power E_T to achieve minimal Bit Error Rate (BER).

The binary sensing network is modeled by the binary CEO problem [11-12], and formulated the minimization problem of obtaining the lower bound on Hamming distortion [13].

Similarly, the problem of optimal power allocation is given in equation (1).

$$\min_{\beta_i} PB(p_1 * d_1, \cdots, p_L * d_L) \quad (1)$$

Where p_i is the error probability of the *i*-th sensor in observing the perceived object. d_i is the error probability of the *i*-th sensor transmits the observed object to the fusion center. Equation (1) under constraints shown in (2), follow as:

$$-\sum_{i\in\phi} H_2(d_i) \le \sum_{i\in\phi} \frac{C(\beta_i E_T)}{r_i} - h(\{p_\phi, \alpha_{\phi c}\} + h(\{\alpha_{\phi c}\})$$
$$\sum_{i=1}^{L} \beta_i = 1$$
$$\beta_i \ge 0 \quad (2)$$

β_i is the energy allocated by *i*-th sensor. E_T is a fixed limited total energy. $C(\beta_i E_T)$ is the *i*-th channel capacity. $H_2(d_i)$ is binary entropy.

3. Proposed Power Allocation Schemes

The formulated problem is non-convex and not easy to solve. The reason is that the analytical from of $h(\cdot)$ is complicated and the parameters $\alpha_{\phi c}$ depend on the allocated power. Moreover, the objective function $PB(\cdot)$ is not convex. We thus propose a brute force search based heuristic method to obtain power ratio, which is summarized in algorithm 1.

However, the computational complexity of algorithm 1 is very high, since the number of combinations on β_i is very large. Even we add a condition that $\beta_i < \beta_j, \forall i < j$ to reduce the number of combinations, the heuristic method is not tractable in practice, particularly for large number of sensors, e.g., $L = 7$.

Hence, we need to formulate this problem instead of using our derived outer bound. To simply this problem, we use the summation of $p_i * d_i$, which is the mean value of this Poisson binomial distribution as the objective function. Furthermore, we suppose that the observations are independent of each other. As a consequence, the equation (1) is formulated to

$$\min_{\beta_i} \sum_{i=1}^{L} (1-2p_i)d_i + p_i \quad (3)$$

Equation (3) under constraints shown in (4), follow as:

$$1\text{-H}_2(d_i) \le C(\beta_i E_T)$$
$$\sum_{i=1}^{L} \beta_i = 1$$
$$\beta_i \ge 0 \quad (4)$$

Algorithm 1 Heuristic method for power allocation

```
Input: p_i , E_T
Output: β_i^* such that d is minimized
1.Initialization: ascending sort p_i , d_=∞
2.For β_1 = 0 to 1 do
3.      For β_j = 0 to 1 − Σ_{k=1}^{j−1} β_k ,(j = 2,⋯, L − 1) do
4.                β_L = 1 − Σ_{k=1}^{L−1} β_k ;
5.                If β_k > β_L ,(∀k > l) then
6.                      Continue;
7.                End If
8.Obtain minimal d_i for each link based on the outer bound and
Calculate d using PB(p_1 * d_1,⋯, p_L * d_L) ;
9.              If d < d_ then
10.                  β_i^* = β_i , i = 1,⋯, L ;
11.                  d_ = d ;          /*update β_i^* and d_ */
12.             End If
13.     End For
14.End For
15.Return β_i^* ;
```

It should be emphasized here that the solution of this problem only provides a suboptimal power ratio of the main problem, since the effectiveness of the correlation is not taken into account. The complexity of the problem, however, is significantly reduced. In equation (3), it is easily found that d_i works as a dummy variable. Due to the fact that d_i is proportional to $-C(\beta_i E_T)$, we reformulate the equation (3) into the following maximization problem.

$$\max_{\beta_i} \sum_{i=1}^{L} (1-2p_i) C(\beta_i E_T) \tag{5}$$

Equation (5) under constraints shown in (6), follow as:

$$\sum_{i=1}^{L} \beta_i = 1 \qquad \beta_i \geq 0 \tag{6}$$

To avoid analytically deriving the inverse function of $H_2^{-1}(\cdot)$. Obviously, the equation (5) is convex, since the capacity function $C(\cdot)$ is concave and the constraints are linear. The KKT conditions of equation (5) are summarized in equation (7).

$$
\begin{aligned}
-\frac{(1-2p_i)E_T}{1+\beta_i^* E_T} - \lambda_i^* + \mu^* &= 0 \\
\beta_i^* &\geq 0 \\
\sum_i \beta_i^* &= 1 \\
\lambda_i^* \beta_i^* &= 0 \\
\lambda_i^* &\geq 0
\end{aligned} \tag{7}
$$

where $i = 1, \cdots, L$, λ_i^* and μ are the introduced Lagrange multipliers for the constraints. It is found that this problem is very similar to the water-filling algorithm [14] in wireless communications, and easily get the analytical solutions for β_i^* from the KKT conditions. we have the analytical solutions for optimum power ratio β_i^* in equation (5), as

$$
\beta_i^* = \begin{cases} \dfrac{1-2p_i}{\mu^*} - \dfrac{1}{E_T}, \mu^* < (1-2p_i)E_T \\ 0, \qquad \mu^* \geq (1-2p_i)E_T \end{cases} \tag{7}
$$

$$
\sum_{i=1}^{L} \max\{0, \frac{1-2p_i}{\mu^*} - E_T\} = 1 \tag{8}
$$

where μ is the Lagrange multiplier for the equality constraint equation (6), we apply the proposed optimal PA scheme to binary information sensing network and make comparison with the uniform PA method.

4. Numerical Results

By using equation (7), the optimal power ratio are obtained for some fixed E_T and sets of observation error probabilities, the results of which are showed in Table 1. Based on these results, it is found that β_i^* is equal to 0 in some cases, e.g., $L = 3$ with $E_T =$ -5 dB. Hence, our proposed scheme can be perceived as a scheduling method in binary information sensor network. In this case, the cluster header sends a control message to those sensors of which the power ratio is 0 to force them into sleeping mode. After a constant time interval, those sensors are activated and report their positions to the cluster header. Our proposed joint decoding algorithm that utilizes the correlation knowledge is adopted in order to obtain the BER performance.

Figure 2 to Figure 4 demonstrate the BER performance versus total SNR using our proposed power allocation scheme and uniform power allocation. For $L = 3$ and $L = 5$, the BER performance using the power ratio obtained from the heuristic method are also presented. From these results, it exhibits that our proposed PA scheme gains around 1.5~ 2 dB in terms of the total power compared to the uniform PA case for the specific observation error probabilities. Compared to the heuristic method, the loss of our proposed PA is very small, 0.5 dB for $L = 3$, while almost no loss for $L = 5$. The loss is relatively large if the BER performance is dominated by a small number of sensors, e.g., the sensor with *p=0.005* in 3-node case dominates the performance. Based on these comparisons, our proposed power allocation scheme can be seen as a good approximation of the main problem. Moreover, the benefit of our proposed power allocation is the low complexity. In heuristic method, 39 and 106 combinations, respectively, were searched for $L = 3$ and $L = 5$ at each

SNR point. As a consequence, the proposed power allocation scheme can be easily applied in practical situations for the binary information sensing compared to the heuristic method.

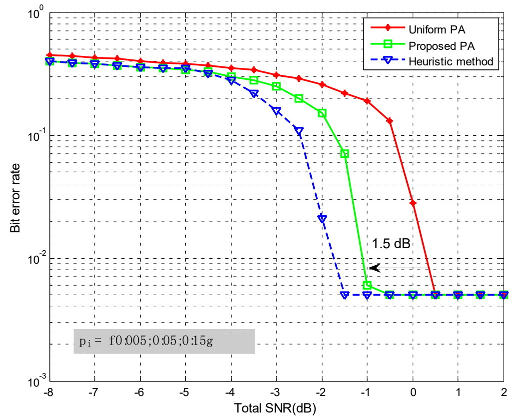

Figure 2: BER performance of using the proposed PA, uniform PA and heuristic method for L = 3.

At the high SNR regime, the BER performance obtained by all the schemes converges together. The reason is twofold:

1) at high SNR regime, the proposed power allocation

Table 1: Optimal power ratio of each sensor obtained by proposed PA scheme.

p_i	$E_T(dB)$	β^*
{0.005,0.05,0.15}	-5 0 10	{0.6745,0.3255,0} {0.529,0.39,0.081} {0.397,0.3517,0.2513}
{0.005,0.01,0.02,0.1,0.3}	-5 0 10	{0.3811,0.3453,0.2736,0,0} {0.3271,0.3137,0.2869,0.0723,0} {0.2595,0.256,0.2487,0.1905,0.0453}
{0.002,0.008,0.01,0.05, 0.07,0.1,0.15}	-5 0 10	{0.3596,0.3174,0.3033,0.0197,0,0,0} {0.2631,0.2479,0.2428,0.1414,0.0904,0.0144,0} {0.1722,0.169,0.1679,0.146,0.135,0.1186,0.0913}

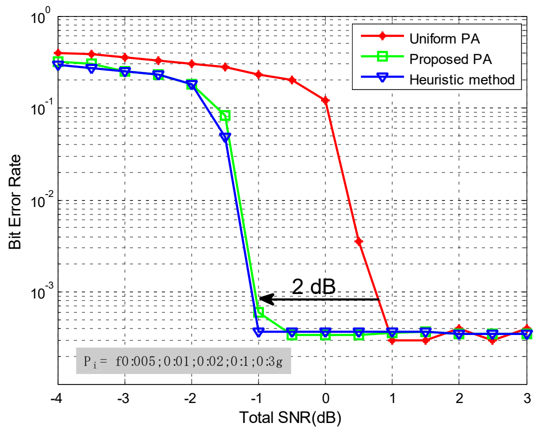

Figure 3: BER performance of using the proposed PA, uniform PA and heuristic method for L = 5.

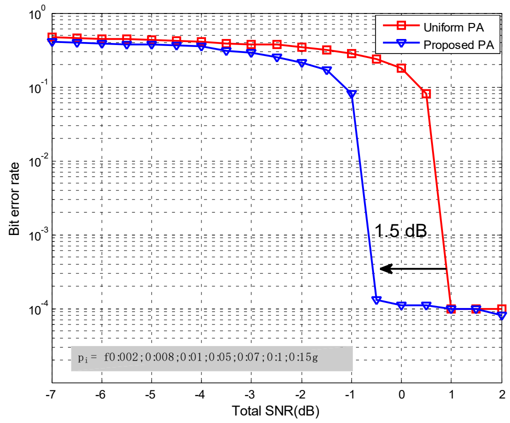

Figure 4: BER performance of using the proposed PA and uniform PA for L = 7.

scheme approaches to the uniform allocation, while in heuristic method, power is uniformly allocated to the dominated sensors; 2) the BER performance is only determined by the error probability p_i when the power is large enough.

The observation error probability p_i is set at predefined values in above analyses, however, Figure 5 illustrates the BER performance of the proposed power allocation scheme when

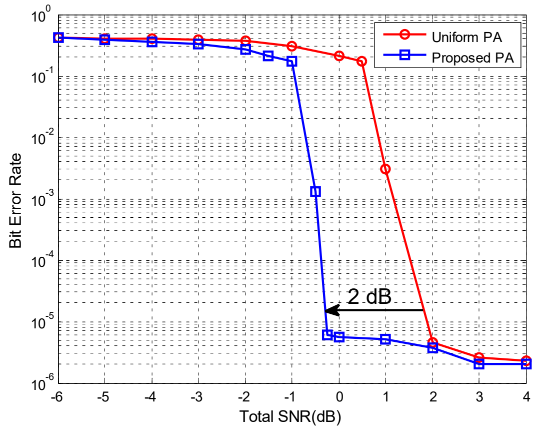

Figure 5: BER performance of using the proposed PA and uniform PA for L = 9. p_i follows logarithmic distribution with ξ = 0.6

p_i follows logarithmic distribution. It is found that the proposed power allocation scheme can achieve 2dB gain in total power compared to the uniform power allocation.

We also consider the power allocation for the case p_i are equally distributed, where the BER performances are illustrated in the Figure 6. The proposed convex optimization method equation (9) results in the same power ratio for each link since the capacity of each link is weighted by the same value.

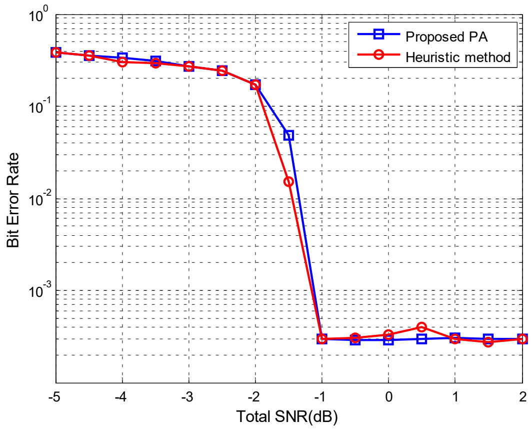

Figure 6: BER performance of using the proposed PA and heuristic method.

However, the heuristic method obtains different power ratio at some SNR points, for example, at -4, -3.5 and -1.5 dB, the optimal power ratio β_i^* are {0.5,0.45,0.05}, {0.45,0.4,0.15} and {0.7,0.15,0.15}, respectively. However, the difference in terms of the BER performance between the proposed power allocation and the heuristic methods is not significant. If p_i is the same, we can simply allocate equal power to each sensor.

In general, our proposed scheme works appropriately, however, the proposed PA is centralized, in which the cluster head needs to collect the information from the sensors. The complexity of the problem may increase if the number of sensors is large in a group. In the future, we need to find a solution to make the PA distributed, and to seek for a good partition method to group sensors.

5. Conclusions

We proposed an optimal power allocation scheme for binary information sensing network form the viewpoint of rate-distortion. For the original formulated problem, we proposed a brute-force search-based heuristic method to get the optimal power ratio. However, it is necessary to check a great number of combinations for the power ratio in the heuristic method. In order to reduce the complexity, we reformulated the optimization problem to maximize the sum of channel capacities weighted by the observation accuracy $(1\text{-}2p_i)$. Through computer simulations, it showed that our proposed power allocation scheme out performs the uniform allocation method and is easy to deploy in practice compared to the heuristic method. Even through our proposed scheme is not distributed, it still be applicable to small-scales sensor network or parallel relaying network. In the future, we need to find a distributed power allocation to reduce the overhead when collecting the information from each senor node by the cluster head.

Acknowledgments

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