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A practical information coverage approach in wireless sensor network

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ABSTRACT

In order to improve energy-effectiveness in wireless sensor network, in practice some sensors in observation points are selected not to gather data. In this case, the insufficient data gathered by the rest of sensors have to cover the total network so that the complete information of the whole environment could be estimated rationally, which is similar to compressive sensing. However, the process of estimation has to cost a lot of energy, which is a crucial problem. This paper proposes a practical and effective information coverage approach in which an actual constrained condition is considered for consensus estimation to reduce unnecessary energy cost reasonably. In our experiments, the method has been proved valuable and feasible.

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1. Introduction

In wireless sensor network, it is vital to guarantee energy-effectiveness for prolonging the lifetime of the network. In this case, some sensors are considered not to gather data to reduce energy cost, by e.g. a sleep schedule [1]. This approach is effective and practical for power-saving. However, environment information of the areas where sleep sensors are deployed cannot be sensed directly, therefore information coverage has been a potential challenge. It means that the rest of sensors (unsleeping or wake) have to estimate these un-sensed areas to perceive the global situation of the network. Consensus estimation [2,3] had been proposed to apply to the values of part of sensors to estimate one of their neighbors. That is, information coverage could be achieved by this scheme rationally. Nevertheless, there is a challenge for current consensus estimation methods in actual applications, which is in that it is unnecessary for all wake sensors to undergo consensus estimation, since some of them have no real effect on estimation. In other words, these approaches have unnecessary information exchange in the procedure of consensus which is bound to waste energy. Hence, an effective information coverage approach should be designed for consensus estimation.

This Letter focuses on the actual constraint in the process of consensus estimation. The previous work of Q. Ling et al. [4] is related to ours. However, our design is more practical for information coverage by distinguishing different wake nodes, and energy cost of computation and communication in the network could be further reduced reasonably. Meanwhile, two influence parameters are adopted to embody the relationship between the number of wake sensors and accuracy of estimation separately to generate the formulation. In our work, we firstly optimize the consensus estimation formulation in practice. In detail, wake sensors are divided into two kinds, one being crucial sensors in whose neighbors there is at least one sleep sensor, and the other is common sensors in whose neighbors there is not any sleep sensors. In addition, wake sensors are considered to be capable of finding a neighboring node waking

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at the same time. Obviously, the environment information of the area where sleep sensors are deployed is relevant to the data closely sensed by crucial sensors and hardly by common sensors. Therefore, in our formulation crucial sensors are considered instead of all wcloselyake sensors in general consensus estimation (GCE). In this case, the practical scheme reduces the computation and communication costs. In order to generate our formulation, the relationship between the number of wake sensors and accuracy of estimation is embodied with two influence parameters. In the process of consensus estimation, each crucial sensor preserves its estimates itself and sleep sensors of its neighbors. Consequently, crucial sensors of theirs neighboring also reach consensus for sleep sensors of their neighbors. As a result, crucial sensors conserve theirs values and numerical estimates of its neighbors. Through values of wake sensors themselves and estimates of crucial sensors, information coverage could be reached. In this method, the number of crucial sensors is similar to the selection of measurement in compressive sensing technique [5] for accurate estimation. Experiments show that our algorithm outperforms general consensus estimation method.

Our contributions in the Letter are summarized as follows:

a) Crucial wake sensors are picked out from all the wake ones for more effective energy saving.
b) The relationship between the number of wake sensors and accuracy of estimation is reflected by two influence parameters for universal formulation.

The rest of this paper is organized as follows. Section 2 introduces briefly related background. Section 3 proposes our optimized algorithm. Experiments in actual environments and simulations are given in Section 4. Finally, conclusions are drawn in Section 5.

2. Background

Consensus estimation, as a decentralized estimation method, is employed to local estimates in wireless sensor network [6,7]. In general, estimators in this scheme are always formulated as a solution of convex minimization problem via iteration. In current methods, every iteration comprises of two steps, one step is communication for interchanging information between sensors and their neighbors and the other step is update for renewing their local estimation via interchanged information. For instance, the sample average estimator was applied to analyze consensus parameters in ensemble learning [8] as an optimization problem. Kar et al. [9] and Thanou et al. [10] discussed respectively two kinds of distributed consensus based on deterministic and random signals.

In the process of estimation, sensors need to dynamically exchange their estimates to neighbor sensors and update their local estimates until the global network converges. By updating local estimations iteratively, the whole network could achieve consensus which minimizes the estimation error. In this case, information will reach global coverage even if not all sensors are available. Therefore, it is suitable to utilize consensus estimation to obtain information of the whole network based on the part of sensors. However, it is crucial to propose an objective optimization function and corresponding constraint condition for better estimation, which is the essential mission of our work.

3. The proposed information coverage algorithm

To estimate precisely and save energy, we adopt valid (or crucial) wake sensors and exclude invalided wave sensors for information coverage. In this Letter, an optimized formulation for consensus estimation is proposed and then information converge algorithm is presented.

3.1. Optimized formulation

Consider a network with N sensors comprised of wake sensors W and sleep sensors S and $N = |W| + |S|$, where $|\bullet|$ denotes cardinality. Sensors i are deployed at the position p_i, $i \in N$. The set of wake sensors W consists of the subset of crucial sensors C_r and the subset of common sensors C_o. The former is defined as a sensor which has at least one sleep neighbor, and the latter is defined as a sensor which has zero sleep neighbors. Both sets satisfy $W = C_r \cup C_o$ and $|W| = |C_r| \cup |C_o|$. Suppose sensors are just single-hop communications, so that the i-th sensor can only communicate with sensor j in its neighborhood $j \in N_i$, $N_i \subseteq [1, N]$. The connectivity of network is symmetric and the topology of the network is an undirected graph whose vertices are sensors and its edges represent available communication links. Environment information is sensed by wake sensors and these local sensed data can provide a well approximated estimate about the global area. Let $e = [e_1, e_2, \cdots, e_N]^T$ denote the environment information vector, where s_i corresponds to be value at p_i. Similarly, $d = [d_1, d_2, \cdots, d_N]^T$ denotes the sensed data by all sensors. Here, d_i is null if the i-th sensor is a sleep sensor. In practice, information occurring at the position p_i may influence its neighborhood A_i. We formulate the influence function $f_i(p)$ which is non-zero only for positions $p \in A_i$ and normalized to obey $f_i(p_i) = 1$. The sensed data d_i can be regarded as the superposition of the influence in the neighborhood of the point p_i.

To achieve consensus estimation, two premises should be satisfied:

Premise 1 *(Connectivity).* The network should be connected based on all sensors or all wake sensors.

Premise 2 *(Influence range).* If the distance of any two sensors is larger than their communication range, their influence function is equal to 0.

For Premise 1, it is easy to employ route algorithms to judge the connectivity of the network. For Premise 2, it is a reasonable assumption since information hardly influences the sensed data in a faraway location. Hence, the function of the communication range of sensors is discussed in Section 4.

Based on two premises, sensed data d_j of sensor j can be represented as $d_j = \sum_i^N f_i(p_j)e_i + n_j$, where $e_i \geq 0$ and

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