

A Data-Centric Self-Organization Scheme for Energy-Efficient Wireless Sensor Networks

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Abstract. In this paper, we propose a new self-organization scheme, DICSIION (Data-centrIC Self-organizatiON), which can improve the energy efficiency and prolong network lifetime of wireless sensor networks. Since a large number of sensor nodes are densely deployed, neighboring nodes may be very close to each other. Therefore, we assume that sensor nodes have a high possibility to collect the duplicate data about the same event. DICSIION can considerably reduce the energy consumption because a zone head only can transmit and receive a representative data to base station or neighboring zone heads after zone formation. Our performance evaluation results demonstrate that DICSIION outperforms to STEM.

1 Introduction

It is important to prolong network lifetime and improve energy-efficiency in wireless sensor networks consisting of sensor nodes with limited energy resources [1]. Hence, in starting to organize a wireless sensor network, energy efficiency of sensor nodes must be considered to prolong network lifetime [2], [3], [5]. Wireless sensor network is different from ad hoc networks in a number of ways; hence, self-organization schemes of ad hoc networks such as GAF(Geographic Adaptive Fidelity) [6] and Span [7] do not immediately apply to wireless sensor networks. Therefore, we analyze the important characteristics and performance improvement components of previous schemes and propose a new, efficient and constructive self-organization scheme for wireless sensor networks.

We also provide a brief overview of major existing schemes. In ASCENT (Adaptive Self-Configuring sEnsor Networks Topologies) [8], the large number

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of nodes deployed in micro-sensor network systems preclude manual configuration, and the environmental dynamics are not able to design pre-configuration. Therefore, nodes have to self-configure to establish a topology that provides communication and sensing coverage under stringent energy constraints. Each node assesses its connectivity and adapts its participation in the multi-hop network topology based on the measured operating region.

STEM (Sparse Topology and Energy Management) [9] dramatically improves network lifetime by exploiting the fact that most of the time, the network is only sensing its environment waiting for an event to happen. Previous topology management schemes have focused on selecting which nodes can turn off their radio without sacrificing the capacity of the network. However, by alleviating the restriction of network capacity preservation, STEM can trade off extensive energy savings for an increased latency to set up a multi-hop path.

Since sensor nodes consisting of wireless sensor networks are deployed in a vast area, they form randomly distributed, dense networks that have a high density in a particular region. Additionally, because sensor nodes in a highly dense area are very close to each other with respect of distance, they have a high probability to collect the duplicate data. Thus, by the transmission and aggregation of the duplicate data in this environment occurs to unnecessary energy consumption [4].

Therefore, we propose a new self-organization scheme for wireless sensor network called DICSION. It reduces the unnecessary energy consumption that a zone is created with the sensor nodes collecting the duplicate data, and only the zone head (ZH), a representative node in a zone, is responsible for the data transmission and sensing function. The rest of the paper is organized as follows. In Section 2, we present our motivations for research. In Section 3, we explain the details of DICSION. Performance evaluations are presented in Section 4 and the conclusions are in Section 5.

2 Motivation

There are two aspects as motivation for this work; sensor node distribution and casual application.

- Sensor node distribution

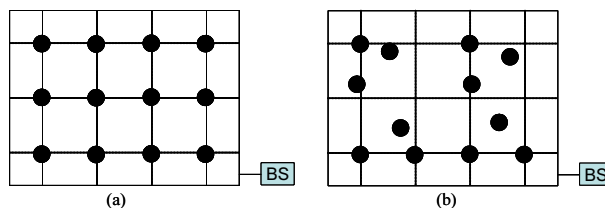


Fig. 1. The distributed sensor nodes. (a) Uniform distribution. (b) Random distribution.

Since a large number of sensor nodes are densely deployed in target environments, neighboring nodes may be very close to each other. In addition, because sensor nodes are unevenly dropped by a plane or helicopter over a sensing field, they create the distributed wireless sensor network as shown in Fig. 1(b).

- **Casual application**

We aim to the casual applications such as weather estimation and environmental monitoring which are required in the user-predetermined value range. In Fig. 1(b), because the neighboring sensor nodes adjoin with each other, the sensed data is very similar.

Because sensor nodes are very close to each other in some regions, they have a high probability to collect the duplicate data. And some applications for wireless sensor networks need a representative value of a min-max range rather than values of all sensor nodes in a zone. Therefore, we focus on developing an energy-efficient self-organization scheme which can fulfill these motivation.

3 DICSION scheme

The main mechanism for DICSION is as following. First, the sensor nodes exchange the location and sensing information through exchanging the Hello messages. At the end of exchanging the Hello messages, they join in each zone according to the reception of a CH_ADV message and the duplicate data detection (3D) algorithm. Second, after the data path setup is achieved between the ZHs of the closest zones (If ZH can not communicate directly with next ZH, it sends the data to next ZH through sensor node close to next ZH), the routing path is created by gradual extension from the source node to the base station (BS). DICSION consists of mechanisms for zone formation, ZH selection, and multi-zone data forwarding.

We present the DICSION architecture, as shown in Fig. 2. Fig. 3 shows the zone formation algorithm of the DICSION. The following sections describe all of these mechanisms in detail.

3.1 Zone formation

We design an algorithm such that there are a certain number of zones, during each round to constitute a good zone formation. Round means that during current ZH is converted to the next ZH like LEACH [11]. When sensor nodes are randomly deployed in target environments, they transmit a Hello message to the neighboring nodes. Then, each sensor node recognizes neighbors by actively transmitting and receiving to the Hello messages including the location information of sensor node and meta data of the initial sensing information. All sensor nodes complete the exchange of the Hello messages and meta data, and then zones are created with sensor nodes that collected duplicate data about

the event. In DICISION, sensor nodes make autonomous decisions without any centralized control. Thus, zone formation can be performed without knowing the exact location of any of the sensor nodes in the network. And we developed a 3D algorithm for zone formation. The boundary of a zone is decided within the radio range of the ZH. Before sensor nodes are randomly deployed in a sensing field, a BS or user sets a B_i to them for data precision. Next, ZH collects all zone information using Hello message and returns it to all z-members. Thus, the z-members possess the zone information and location information of the neighbors. We assume that only ZH becomes active state and z-member remains in sleep state. Finally, the Data message including the representative data of a ZH is delivered to BS. And sensor nodes automatically update their neighbors by periodically sending and receiving Hello message. The 3D algorithm consists of two steps and the sensor nodes satisfied with two steps belong to the same zone.

- Step 1: The sensed data of any sensor node, X_i is defined A_i and the sensed data of S_i is defined as B_i where $B_i \in A_i \pm \Phi$ (Φ : user-predetermined range) and Φ is a min-max range to raise for the accuracy of the representative data (not aggregated data).
- Step 2: The set of the z-member, M_i , of ZH, Z_i , is defined as $R \geq M_i = [S_i || d(Z_i, S_i)]$ where S_i represents the sensor nodes with the exception of ZHs. Let $d(Z_i, S_i)$ be the distance from Z_i to S_i and R is radio range of Z_i .

Fig. 4 shows the state transition and message process of sensor node. In the first time sensor nodes are deployed in target environments, they step into a neighbor discovery phase(①). Sensor nodes in neighbor discovery phase have no energy consumption due to only receiving signals. After all sensor nodes have exchanged Hello messages with each other, only ZH elected through ZH selection algorithm is to be active state (②) and the z-members are to be sleep state(③). As a network operation's time goes on, if the residual energy of ZH falls below a threshold value, $E_{threshold}$, the sleep sensor node having the highest residual energy level among neighbors is transited to the active state through a Wakeup message received from its ZH(④). In addition, after the previous ZH receives an Ack message from the new ZH, it goes into sleep state(⑤). Table 1 shows the message types and functions.

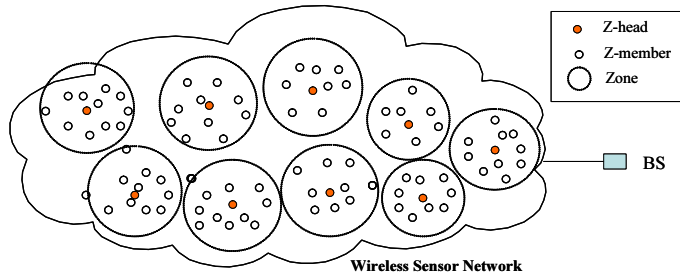


Fig. 2. DICISION architecture.

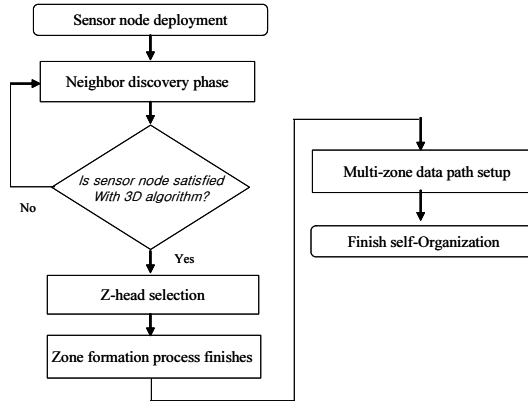


Fig. 3. The zone formation algorithm of DICSION.

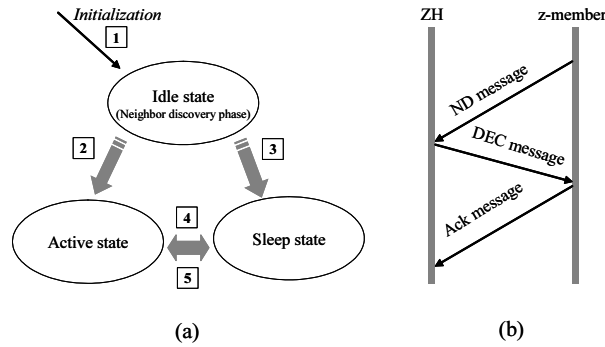


Fig. 4. The state transition (a) and message process (b) of a sensor node.

If re-clustering of LEACH frequently occurs, the processing overhead of this procedure can be significant [11]. Thus, we limit the case to re-formation of DICSION in two conditions. And sensor nodes are keeping their connectivity through periodically mutual communications using Hello messages.

- Condition 1: when the residual energy of ZH falls down to the threshold value ($E_{threshold}$).
- Condition 2: when the z-member senses to the different data about the same event within a zone.

3.2 ZH selection algorithm

When the neighbor discovery phase terminates, the ZH is randomly selected with a modified probability function of cluster head (CH) selection algorithm in LEACH protocol [11]. The rest of the sensor nodes of the zone, z-members, are to

Table 1. Message types and functions

Message types	Functions
Data	It consists of a sensing data and the information of sensor node.
Neighbor Discovery(ND)	It is used for neighbor discovery phase.
Hello	It is used that sensor nodes exchange with their information about location and state.
DEC	It is used that ZH notifies sensor nodes of joining or not in its zone.
Ack	It is a response to DEC message.
Wakeup	It is used for state transition of sensor node.
ZH Advertisement(ZH_ADV)	It is used that ZH advertises its information to z-members and the remaining ZHs.

be sleep. In a proposed scheme such as LEACH, sensor nodes elect themselves to be ZHs at the beginning of round $r + 1$ (which starts at time t). This probability is chosen such that the expected number of ZHs for this round is k . thus:

$$E[\#ZH] = \sum_{i=1}^N P_i(t) = k \tag{1}$$

The first time ZH selection is randomly achieved, but for the next ZH selection, we use the energy-priority mechanism that selects a new ZH as a z-member (sleep sensor node) having a highest residual energy in a zone. The z-members periodically determine whether they should become a ZH. Where, N is the total number of nodes in the network. Ensuring that all nodes are ZHs the same number of times requires each node to be a ZH once in N/k rounds. Combining these constraints gives the following for each node i to be a ZH at time t :

$$P_i(t) = \begin{cases} \frac{k}{N - k \cdot (r \bmod \frac{N}{k})} & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} \tag{2}$$

Where, r is the number of rounds that have passed $C_i(t) = 0$ and if node i has already been a ZH in most recent ($r \bmod N/k$) rounds and 1 otherwise. Therefore, only nodes that have not already been ZHs and which presumably have more energy available than nodes that have recently performed this energy-intensive function, may become ZHs at round $r + 1$ [11]. In the next rounds after initial round, ZHs are selected using the energy-priority mechanism described in Eq. (3),(4). A previous ZH is put into sleep state when it receives an Ack message from a new ZH. The z-members determine whether they should become ZH through energy-priority equation:

$$z - members = \{Z_1, Z_2, \dots, Z_n\} \tag{3}$$

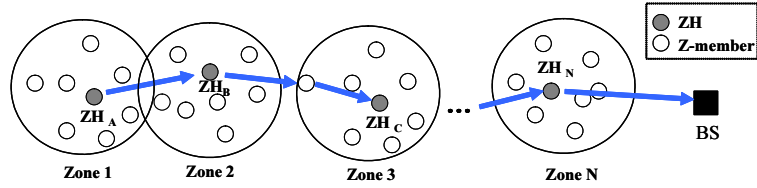


Fig. 5. Multi-zone data forwarding of DICSION.

$$ZH_{next} = [Z_i | \max E_{Z_i}], i = \{1, 2, 3, \dots, n\} \quad (4)$$

Where, Z_n is the total number of z-members in a zone. The energy priority mechanism is used to elect z-member having a highest residual energy as ZH in a zone through the Wakeup message before the residual energy of a current ZH goes below the threshold value ($E_{threshold}$). A z-member, Z_i , elects itself to be a ZH_{next} through result of energy-priority function before the initial ZH is to be sleep. ZHs broadcast ZH_ADV messages to other ZHs in a network. A ZH_ADV message consists of a ZH identifier (ID) and header. Thus, ZHs keep their connectivity to each other through exchanging of ZH_ADV messages.

3.3 Multi-zone data forwarding

We use a multi-zone data forwarding mechanism as shown in Fig. 5. When the Data message arrives at the ZHs of every zones, it is then aggregated to one unit of the same size and transmitted to next ZH. If ZH can not communicate directly with next ZH, it sends the data to next ZH through sensor node close to next ZH. Therefore, the multi-zone data forwarding mechanism is more energy efficient than flat routing because all sensor nodes are participated in routing. Fig. 5 shows the data dissemination from ZH_A of zone 1 to BS.

In conclusion, the multi-zone data forwarding in DICSION can improve the reliability of data dissemination and conserve energy in wireless sensor networks in proportion to the reduction of energy consumption of ZHs that join the data path setup.

4 Performance Evaluation

In this section, we evaluate the performance of the DICSION via theoretical analysis and simulations.

4.1 Theoretical analysis

We compare DICSION($E_{node}^{DICSION}$) with STEM(E_{node}^{STEM}) and basic scheme (E_{node}^{Basic}) with regards energy consumption of wireless sensor networks on increasing the number of sensor node. In our analysis, we use the same radio model discussed in [5]. The total energy consumption by a node during a round can be broken

Table 2. Power characteristics of sensor node.

Radio mode	Power consumption
Transmit	14.88mW
Receive	12.50mW
Idle	12.36mW
Sleep	0.016mW

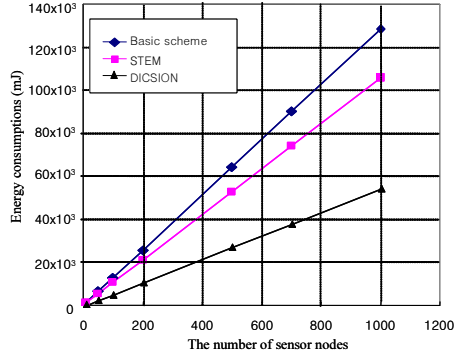


Fig. 6. Theoretical result.

up into two components, one for each frequency band of the radio model. In Eq. (5), E_{total} is the total energy consumption of sensor network, E_{active} is the energy consumption of ZH, and E_{sleep} is the energy consumption of sleep sensor node. Wireless sensor network has a number of sensor nodes, N , and each term multiplies N_{active} or N_{sleep} .

$$E_{total} = N_{active} \cdot (P_{tx} \cdot t_{tx} + P_{rx} \cdot t_{rx}) + N_{sleep} \cdot P_{sleep} \cdot t_{sleep} \quad (5)$$

In basic scheme, the total energy would be equal to (6). P_{data} contains contributions of P_{idle} . The main difference is that the radio is never energy-efficient in the sleep state [5]. In this equation, t_{data} is the total time the radio is turned on for communication data. As a result, P_{data} contains the packet transmission, packet reception, and idle power [7].

$$E_{node}^{Basic} = P_{idle}(t - t_{data}) + P_{data} \cdot t_{data} \quad (6)$$

In STEM, the equation of energy consumption is simple as (7) [7]. The P_{node} is a combination of sleep and idle power [5].

$$E_{node}^{STEM} = P_{idle}(t - t_{data}) + P_{setup} \cdot t_{setup} + P_{sleep}(t - t_{data}) + P_{data} \cdot t_{data} \quad (7)$$

In DICSION, because sensor nodes stay in the sleep phase rather than idle phase in many cases, the P_{idle} becomes negligible. And we have an Eq. (8).

$$E_{node}^{DICSION} = \frac{P_{sleep} \cdot (t - t_{tx}) \cdot (t - t_{setup})}{t} + P_{setup} \cdot t_{setup} + P_{data} \cdot t_{data} \quad (8)$$

Because sensor node can transit to various states until its battery is empty, we can not model the energy consumption in each state of sensor node. Therefore, we use the energy model that generalized energy consumption during periodic time, t . Some representative power numbers for the different modes are summarized in Table 2 [10]. In this paper, performance analysis is achieved in an environment with characteristics of time is $t = 10s$, $t_{setup} = 4s$, $t_{data} = 2s$. For our analysis, we use a 1000-node network, which is randomly distributed in a sensing field.

As shown in Fig. 6, this graph results in energy consumption about each scheme. Energy consumption of all schemes increases with the increase of number of sensor nodes, but the DICSION is smaller than the basic scheme and STEM. Therefore, the proposed scheme has a good energy-efficiency and prolongs network lifetime.

4.2 Simulation results

In this section, we compare the performance of the DICSION and STEM. Simulations were performed using the MATLAB simulation tool [12]. DICSION assumes that there are N nodes distributed randomly in a square. The network dimension studied is $200m \times 200m$ and BS is located at (300, 300) on remote location. We executed 50 runs of the simulation for each scheme. The readings from these 50 trials for more accurate because sensor nodes are randomly distributed in target environments were averaged and plotted. Fig. 7 compares the energy consumption of the DICSION and STEM protocol versus the number of sensor nodes and the number of ZHs. For our simulation, the number of sensor nodes is varied as 100, 200, and 300 and the ratio of ZH is increased with 3%, 4%, and 5%. The ratio of ZHs adopts the optimal number of CH produced in LEACH. As seen in Fig. 7, DICSION is more energy-efficient than STEM.

5 Conclusion

We propose a new self-organization scheme, DICSION, to improve energy efficiency and network lifetime in wireless sensor networks which have a high possibility of collecting the duplicate data by sensor nodes because they are unevenly deployed in sensing field. DICSION considerably reduced energy consumption because only ZH can transmit and receive data after zone formation and the rest sensor nodes are in the sleep state. Performance evaluation demonstrates that DICSION outperforms to STEM.

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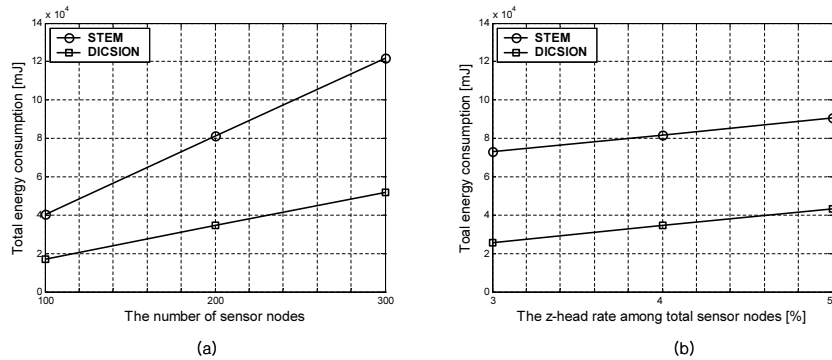


Fig. 7. A comparison of DICSION and STEM with respect to energy consumption. (a) according to the number of sensor nodes. (b) according to the rate of ZHs.

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