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# A Cycle-Based Approach for Data Aggregation in Grid-Based Wireless Sensor Networks

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## Abstract

In this paper, we propose a Cycle-Based Data Aggregation Scheme (CBDAS) for grid-based wireless sensor networks (WSNs). The whole sensor filed is partitioned into a 2D logical grid of cells. Each cell has a head responsible for aggregating its own data with the data sensed by the others in the same cell and then transmitting out. In order to efficiently and rapidly transmit the data to the base station (BS), we link each cell head to form a cyclic chain. Each cell head on the cyclic chain takes turn becoming cycle leader responsible for transmitting data to the BS. As a result, the transmissions are reduced so that it greatly extends the lifetime of the whole WSN. Simulation results show that the proposed CBDAS extends the lifetime of sensor nodes so as to prolong the lifetime of the whole network.

**Keyword:** *Base station, cell head, data aggregation, grid-based, wireless sensor networks.*

## 1. Introduction

Advances in sensor technology, wireless communications, and digital electronics have made it possible to develop low-cost, low-power and multi-functional small sensor nodes. A wireless sensor network (WSN) can be employed in many applications such as environmental and habitat monitoring, target tracking, object detection, and intelligent transport monitoring [1–3].

In WSNs, sensor nodes are typically powered by batteries so that their energy is restricted. Generally, it is impractical to recharge or replace the batteries of the senor nodes in such a harsh environment. The energy consumption of sensor nodes is mainly used in data transmission, especially for a long drive. This paper mainly addresses the problem of data transmission from sensor nodes to a remote base station (BS), where the end-user can access the data. Since the location of the BS is distant, the energy consumed by each node to directly transmit its data to the BS is considerable, and nodes will die very soon. Therefore, it is important for an approach to use as few transmissions as possible to the BS and reduce the amount of data that needs to be transmitted to the BS.

Lots of improved approaches have been proposing [4–5]. Firstly, only a few nodes are responsible for forwarding the data to the BS instead to reduce the data transmissions. On the other hand, the forwarding sensor nodes aggregate their own data with the data sensed by others and then transmit out to reduce the amount of data transmitted to the BS. Aggregated data moves from node to node, and finally a designated node transmits to the BS. Therefore, it is our design goal to evenly distribute the energy consumption of sensor nodes to extend the lifetime of each sensor, so as to prolong the lifetime of the whole WSN.

In this paper, we present a Cycle-Based Data Aggregation Scheme (CBDAS) for grid-based wireless sensor networks. In order to extend the lifetime of a WSN, we build a grid-based infrastructure by partitioning the whole sensor field into a 2D logical grid of cells. Each cell has a head, the one with most residual energy. Each cell head is linked to form a cyclic chain. In each round, one cell head takes turn as cycle leader responsible for directly transmitting data to the BS. In CBDAS, all sensor nodes periodically transmit the sensed data to its cell head. After receiving the data from the others of the same cell, the cell head aggregates with its own data and then sends out. Only cell heads need to transmit data to the cycle leader. The other sensor nodes just fall into sleep mode based on GAF protocol [6].

The rest of this paper is organized as follows. Section 2 briefly reviews some related work. In

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Section 3, our proposed scheme is described. The simulation results are discussed in Section 4. Finally, Section 5 draws the conclusion.

## 2. Related Work

Many routing protocols have been developed to maximize the lifetime of while WSNs in recent years. Among of those, we roughly review some of relevant designs.

LEACH [7] combines the ideas of cluster-based routing and media access together with application-specific data aggregation for WSNs. In LEACH, distributed clusters are self-organized by the nodes in the local cluster. Each cluster has a head responsible for aggregating data and transmitting data to the remote BS. LEACH incorporates randomized rotation of cluster head position to evenly distribute the energy load among all the nodes so as to prolong the system lifetime. TTDD [8] builds the grid on a per-source basis. A source transmits data by building a grid structure. Each grid point has a dissemination node responsible for storing and forwarding data. A sink sends the immediate dissemination node a query which is in turn forwarded towards the source. The query forwarding process lays the information of the path to the sink to enable the requested data from the source to the sink.

PEGASIS [9] links all sensor nodes with a greedy algorithm to form a chain. Each node receives from one neighbor data fused with its own and then transmits to the other on the chain. Gathered data moves from node to node along the chain and finally a designated node called leader transmits to the BS. To reduce the average energy spent by each node per round, nodes take turns transmitting to the BS. PBDAS [10] is for grid-based WSNs with a single chain, formed by repeatedly linking the cell heads from the farthest row left to right then the next farthest row right to left until the nearest row of the BS. In PBDAS, choosing a cell head according to the energy level increases the lifetime and robustness of the WSN.

## 3. The proposed Scheme

The proposed scheme has three primary phases: grid construction, cycle formation, and data transmission. We start with grid construction in Subsection A. Subsection B describes cycle formation. Finally, data transmission is stated in Subsection C.

### 3.1. Grid Construction

In CBDAS, the whole sensor field is partitioned into a 2D logical grid of $M \times N$ cells, where $N$ is even. Each cell has an ID with sensor nodes. A sensor node can calculate its cell ID [$C_x$, $C_y$] from its geographic location ($x$, $y$) as follows:

$$C_x = \left\lfloor \frac{x - x_0}{\alpha} \right\rfloor, C_y = \left\lfloor \frac{y - y_0}{\alpha} \right\rfloor, \qquad (1)$$

where ($x_0$, $y_0$) is the location of the virtual origin set at the network initialization stage, $\alpha$ is the cell size, and $\lfloor k \rfloor$ is the largest integer not greater than $k$. For simplicity, we assume that all cell IDs are positive.

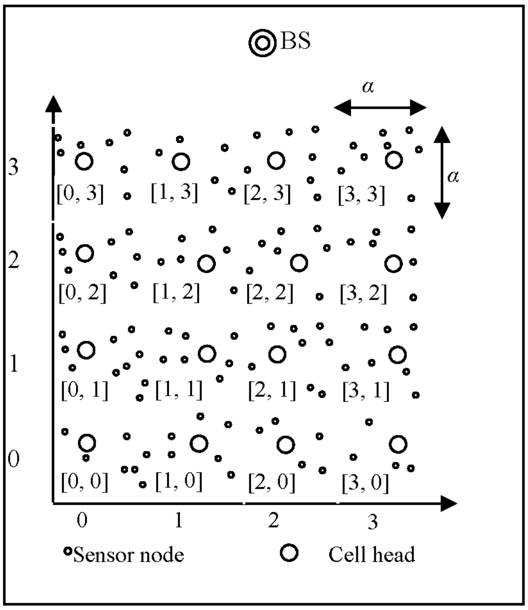

Fig. 1. The logical grid structure.

We take 4 × 4 cells as an example, as shown in Fig. 1. From left to right, the cell IDs are [0, 0], [1, 0], [2, 0] and [3, 0] in the first row, the cell IDs are [0, 1], [1, 1], [2, 1] and [3, 1] in the second row, and so on and so forth.

Each sensor node computes itself which cell it belongs to by (1). All member nodes in each cell determine their own unique sequence numbers by using simple HELLO protocol. Besides, every node maintains a table to keep its own sequence number, geographic location, cell ID, and the current cell head.

In CBDAS, each cell has a head responsible for aggregating data transmitted from the other sensor nodes of the same cell and then transmitting to the neighboring cell head toward the cycle leader.

## 3.2. Cycle Formation

For simplicity, the node with the smallest sequence number acts as the cell head in each cell for the first round. The choice of a cell head for the first round is based on the assumption that all nodes start with an equal energy level. Since a cell head node consumes much more energy than a non cell head node. From the second round, the node with the most residual energy subsequently takes turn being the cell head. Consequently, the energy load of being a cell head is evenly distributed among the nodes. Once the first round cell head of each cell is determined, it starts clockwise finding its downlink cell head in the neighboring cell by using Algorithm 1. After determining its downlink, the cell head with cell ID [$C_x$, $C_y$] sends a *Cycle_forming* packet containing its own cell ID to the downlink. After receiving the packet, the downlink cell head saves the information and replies a *Cycle_reply* packet containing its own cell ID to the uplink cell head from which it receives the *Cycle_forming* packet. Likewise, the uplink cell head saves the information in the *Cycle_reply* packet. In this way, the cell head in each cell caches the information of its uplink and downlink. The cell heads of the whole network are finally linked together to form a cyclic chain, as shown in Fig. 2. As a result, the data can be simultaneously transmitted both clockwise and counter-clockwise in CBDAS.

**Algorithm 1**
**FindDownlinkCell** (CELL)

```
{
  δx = δy = 0;
  If (CELL.Cx == 0)        // The cells of the leftmost column
      If (CELL.Cy == N-1) δx = 1;     //The cell of left top
      Else δy = 1;
  Else If (CELL.Cx == M-1)      // The cells of the rightmost column
      If (CELL.Cy % 2 == 0) δx = -1;
      Else δy = -1;
  Else If (CELL.Cx == 1) δy = -1;      // The cells of the second column
  DOWNLINKCELL.Cx = CELL.Cx+δx;
      DOWNLINKCELL.Cy = CELL.Cy+δy;
      return DOWNLINKCELL;
}
```

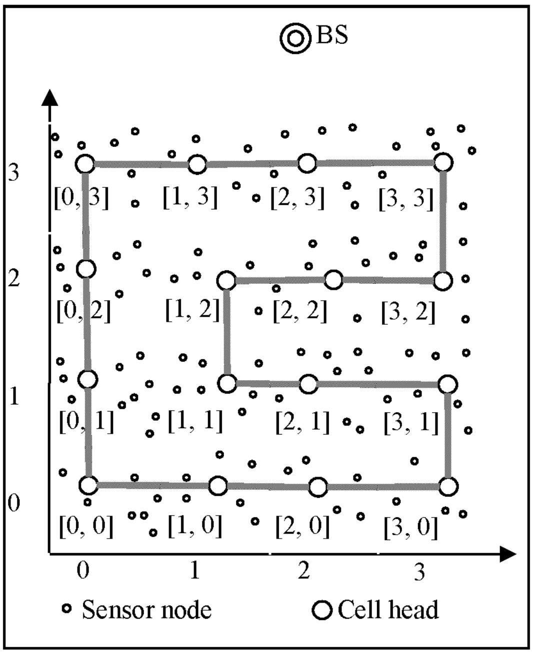

Fig. 2. A cyclic chain.

## 3.3. Data Transmission

In the first round, the BS chooses the nearest cell head as the cycle leader responsible for receiving data from its two neighboring cell heads, aggregating with its own data, and then transmitting the aggregated data to the BS. For simplicity, the cell heads along the cyclic chain clockwise take turns being cycle leader in the next round.

For gathering data in each round, after receiving the request from the BS, the cycle leader will send two tokens $t_1$ and $t_2$ to its two neighboring cell heads respectively. Token $t_1$ will be passed recursively along the cycle clockwise to the next cell head. Conversely, token $t_2$ will be passed recursively along the cycle counter-clockwise to the next cell head. Once a cell head receives the second token from the other direction, it drops the token and disconnects the cyclic chain, making itself as one end and the sender of the second token as the other end. As a result, both end cell heads respectively transmit their own aggregated data to cycle leader in the opposite direction.

For example as shown in Fig. 3, when cell head $e_1$ receives the second token $t_2$ passed along the cycle counterclockwise, it drops $t_2$ and disconnects the cycle, making itself as one end and $e_2$ as the other end. Likewise, when cell head $e_2$ receives the second token $t_1$ passed along the cycle clockwise, it drops $t_1$ and disconnects the cycle, making itself as one end and $e_1$ as the other end. Accordingly, both $e_1$ and $e_2$ respectively transmit their own aggregated data to cycle leader in the opposite direction.

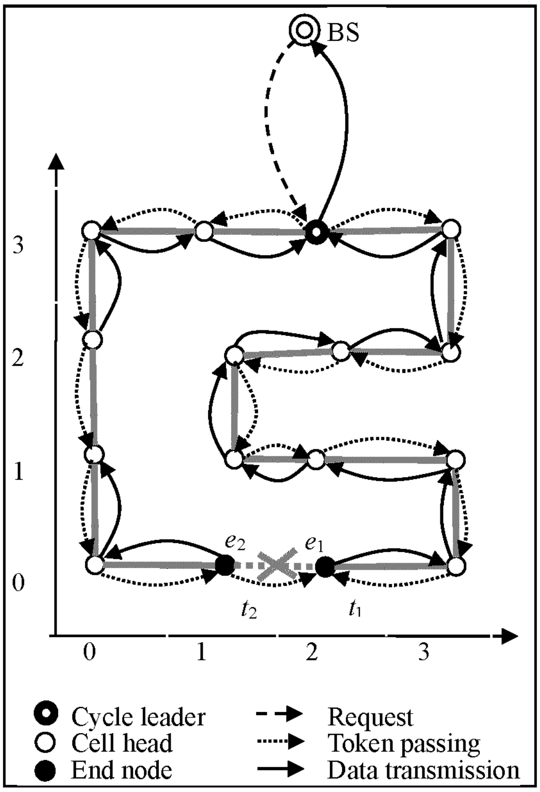

Fig. 3. Data gathering for each round.

## 4. Simulation Results

The effectiveness of our scheme for transmitting the gathered data to the BS is validated through simulation. In this section, we present some of the performance results.

### 4.1. Simulation Model

We use the first order radio model [1] to evaluate the energy consumption of each node. According to this model, a radio dissipates $E_{elec}$ = 50 nJoule/bit to run the transmitter or receiver circuitry. $E_{elec}$ is the energy consumption of the circuit itself. Assuming $d^2$ energy loss, where $d$ is the distance between nodes, a transmission amplifier at the sender node further consumes $E_{amp}d^2$, where $E_{amp}$ = 100 pJoule/bit/m$^2$. $E_{amp}$ is the energy consumed by the amplifier when transmitting packets. Thus, to transmit a $k$-bit message a distance $d$ using this radio model, the radio expends:

$$E_{Tx}(k, d) = E_{elec}\times k + E_{amp}\times k\times d^2 \qquad (2)$$

and to receive this message, the radio expends:

$$E_{Rx}(k) = E_{elec}\times k \qquad (3)$$

Receiving a message is not a low cost operation using these parameter values. Protocols should thus try to minimize not only the transmission distances but also the numbers of transmission and reception operations for each message. We can generalize the total transmission consumption as follows:

$$E_{total}(k) = (E_{elec}\times k + E_{amp}\times k\times d^2) + (E_{elec}\times k) \quad (4)$$

In our simulations, the packet length $k$ is set to 2000 bits and the energy consumed for data aggregation is assumed 5 nJ/bit/message.

### 4.2. Performance Analysis

In the following, we compare the performance of CBDAS with that of Direct, PEGASIS [9], and PBDAS using several random 2000-node networks. Direct approach is simply for each node to transmit its data directly to the BS. PBDAS (Path-Based Data Aggregation Scheme) is also for grid-based wireless sensor networks with a single chain, formed by repeatedly linking the cell heads from the farthest row left to right then the next farthest row right to left until the nearest row of the BS. In CBDAS, the BS is located at (1000, 1500) in 2000 m × 2000 m field partitioned into a grid of 10 × 10 cells. We conducted the simulations to verify the number of rounds when 1%, 20%, 50%, and 100% of nodes die for each scheme with each node having the same initial energy level.

Fig. 4, Fig. 5, and Fig. 6 show the number of rounds until 1%, 20%, 50%, and 100% of nodes die for a 2000 m × 2000 m network with initial energy level 0.25 J, 0.5 J, and 1.0 J per node, respectively. As shown in the figures, CBDAS outperforms Direct, PEGASIS, and PBDAS in all cases. As expected, CBDAS extends the lifetime of sensor nodes so as to prolong the lifetime of the whole network.

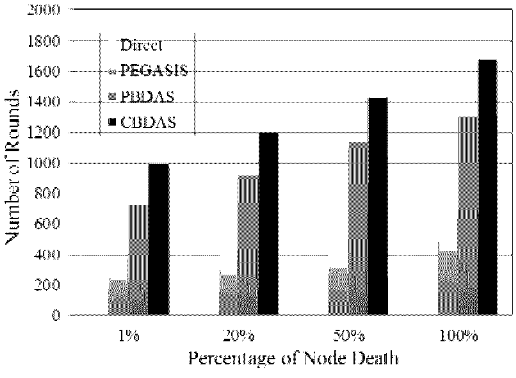

Fig. 4. Performance results for the network with 0.25 J/node initially.

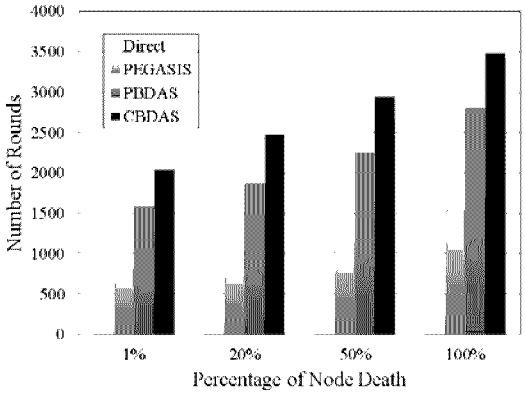

Fig. 5. Performance results for the network with 0.5 J/node initially.

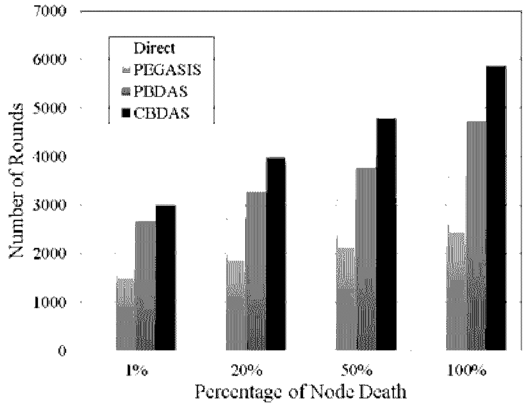

Fig. 6. Performance results for the network with 1.0 J/node initially.

## 5. Conclusions

In this paper, we proposed a grid-based WSN to transmit the gathered data to the BS. In terms of the overhead for building the grid structure, we only constructed the grid infrastructure once in the initial phase. Each node determines which cell it belongs to simply by an arithmetic operation. The formation of the cyclic chain is easy. Only the cell heads on cyclic chain need to forward data to the cycle leader then to the BS. To decrease the energy load of cell heads, the node with most residual energy is chosen to be cell head. Besides, cell heads take turns being cycle leader to transmit data to the BS so that the energy depletion in the network is evenly distributed. As a result, the lifetime of the sensor nodes extends so as to prolong the lifetime of the whole network. Simulation results show that the proposed CBDAS outperforms Direct, PEGASIS, and PBDAS.

## Acknowledgment

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