Journal of System Simulation

Volume 31 | Issue 4 Article 21

11-20-2019

Extending Lifetime of Sensor Networks Based on Sleep-scheduled Routing Algorithm

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Keywords

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Recommended Citation

Pan Zhuojin, Stuart D. Semujju, Luo Zhen, Yang Hua. Extending Lifetime of Sensor Networks Based on Sleep-scheduled Routing Algorithm[J]. Journal of System Simulation, 2019, 31(4): 765-770.

第 31 卷第 4 期
2019 年 4 月
系统仿真学报©
Journal of System Simulation
Vol. 31 No. 4
Apr., 2019

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基于休眠调度的传感器节点寿命延长路由算法

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摘要：在无线传感器网络中，为了使节点能量消耗最小，本文提出一种节能休眠调度树形路由协议(EESSTBRP)，*其修改 PEGASIS 中链的形成，依据距离和感测范围创建网络中成对和不成对的节点。成对节点在活动和休眠模式间切换*，从而消除冗余数据，节省电池能量；*为减少节点在模式之间切换消耗的能量，该协议利用节点能量接近耗尽的点完成转换*；为进一步减少能量消耗，该协议利用基于 Prim 算法的最小生成树机制将数据从活动节点路由到基站。仿真结果表明，与 PEGASIS 相比，该协议能够提高网络寿命。

关键词：网络寿命；休眠调度；剩余能量；感测范围

中图分类号：TP391　　文献标识码：A　　文章编号：1004-731X (2019) 04-0765-06

DOI: 10.16182/j.issn1004731x.joss.17-0104E

Introduction

Wireless Sensor Networks (WSNs) consist of several small, cheap, low-power wireless sensors[1]. WSNs are used in a wide range of applications such as area monitoring, land slide detection, industrial detection, health care monitoring etc[2]. WSNs are of significance to the evolution of Internet of Things (IoT). IoT is envisioned to have over fifty billion new connections by the year 2020[3]. The key challenge in WSNs is designing energy efficient routing

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Received: 2017-03-07　　Revised: 2017-07-04;
Foundation item: Science and Technology Foundation from the Liaoning Education Department (L201626), AVIC Aeronautical Science Foundation (2014ZC54012), Science and Technology Foundation of Liaoning Province (2013024002);
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mechanisms to minimize energy consumption in the network. One of the emerging trends of minimizing energy consumption during routing in sensor networks is the use of the sleep scheduling concept[4-6]. This concept involves switching off some unnecessary nodes sensing the same data so as to remove redundant data and save battery power. However, significant amount of energy is consumed if nodes frequently switch between sleep and active modes[7]. This issue is considered in the design of EESSTBRP. A number of energy-efficient routing protocols for WSNs have been proposed by researchers. Power-Efficient GAthering in Sensor Information Systems(PEGASIS)[8] is a chain-based protocol in which a chain is constructed to connect all the nodes in the network by using the greedy algorithm. Data is transmitted along the chain to a chain leader which aggregates the data and transmits it to the BS. However, there is a bottle neck problem due to single chain leader. Also, there is no consideration of residual energy of nodes and distance from the BS during selection of the chain leader[9]. Moreover, long links inevitably exist in the chain[5]. Geography-Informed Sleep Scheduled and Chaining Based Routing (GSSC)[4] selects one node with maximum remaining energy in each round as the active node among nodes in a small area while the other nodes take up a sleep mode. The active nodes forward their data along a chain to the BS. However, nodes consume large amount of power by using Geographic Positioning System (GPS)[10]. Moreover, energy is consumed during frequent switching between active and sleep modes. This occurs due to the criteria of choosing a node with highest residual energy as the active node in each round. In Ref. [5], the Sleep Scheduled and Tree-Based Clustering (SSTBC) routing protocol uses a centralized algorithm to select one node with maximum remaining energy in each round as the active node in a grid while the other nodes in that same grid take up a sleep mode so as to save battery power. The active nodes forward their data along a tree to the BS. However, there is significant energy consumption due to frequent switching between active and sleep modes. The remainder of the paper is organized as follows: The network and radio model is discussed in Section 1. Section 2 describes the proposed EESSTBRP scheme. Section 3 is the simulation and analysis of results. Finally, section 4 concludes this paper.

1 Network and radio model

The proposed scheme considers the following network model assumptions:

- Sensor nodes are randomly deployed densely within a target field and there is only one BS deployed at the center of the network area.
- Sensor nodes are stationary and energy constrained.
- The BS is stationary but is not energy constrained.
- All sensor nodes are homogeneous and have same capabilities of sensing a target area, processing data and ability to change the power level to communicate with the BS directly.
- All links are symmetric[8].
- Each node has its unique identifier (node ID)[11].

For analysis of the radio model in EESSTBRP, we assume a first order radio energy dissipation model as in Ref. [8, 12]. The amount of energy consumption for transmitting a k-bit data packet over a distance, d is given as follows:

$$E_{TX}(k,d)=E_{elec}*k+E_{fs}*k*d, \text{ if } d<d_0 \quad (1)$$

$$E_{TX}(k,d)=E_{elec}*k+E_{amp}*k*d^4, \text{ if } d\geqslant d_0 \quad (2)$$

For receiving k-bit data, the amount of energy consumption is

$$E_{RX}(k)=E_{elec}*k \tag{3}$$

In this model, a radio dissipates E_{elec} to run the transmitter or receiver circuitry. E_{fs} (free space) and E_{amp} (multi-path fading) refer to the amplifier energy consumption coefficient when the transmission distance is less than and greater than or equal to the threshold distance, d_0 respectively which is determined as:

$$d_0=\sqrt{\frac{E_{fs}}{E_{amp}}} \tag{4}$$

2 Proposed EESSTBRP scheme

The proposed scheme is divided into five phases: set-up phase which consists of area dividing and one-hop neighbor node pairing, sleep scheduling phase, cluster head selection phase, minimum spanning tree formation phase and data transmission phase.

2.1 Set-up phase

2.1.1 Area dividing

Initially, all the nodes in the network send a HELLO message containing their node ID and residual energy to the BS. From this information, the BS is able to establish location of the nodes using positioning algorithms such as Received Signal Strength Indicator (RSSI). The BS then divides the network area into four consecutive regions each having equal number of nodes.

2.1.2 One-hop neighbor node pairing

According to[7], if a node, s_i is located at a known coordinate (xs_i , ys_i), and has a sensing range, Rs_i ,the euclidean distance, between node s_i and its neighbor node, s_j , is computed as follows:

$$d(s_i,s_j)=\sqrt{(x_{si}-x_{sj})^2+(y_{si}-y_{sj})^2} \tag{5}$$

If a node $s_{j,}$ is close to node s_i then it is considered an internal sensor of node s_i as in Eq.(6). Therefore, both nodes will sense the same target point.

$$d(s_i,s_j)\leqslant Rs_i \tag{6}$$

In analysis of the PEGASIS chain as shown in Fig 1, nodes s_2 and s_3 are covering the same target point, *X*. Considering the Eq.(6), node s_2 is an internal sensor to node s_3. If both of these two sensors, s_2 and s_3 sense and transmit data about point *X*, this introduces redundancy and a waste of battery power.

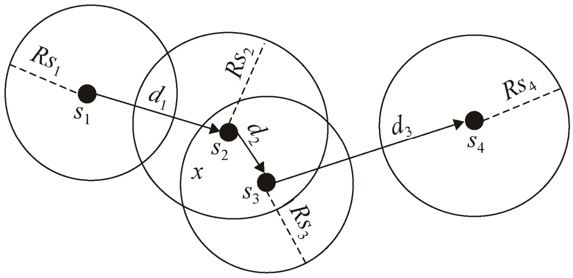

Fig. 1 Redundancy in PEGASIS chain

In the proposed scheme, the BS uses the greedy algorithm to find each node's close neighbor and follows a distance and sensing range threshold to establish a set of paired and unpaired nodes in each region as shown in Fig 2 and detailed in Fig 3. The paired nodes are assigned a paired status while the unpaired nodes maintain an unpaired status such as in Ref. [6].

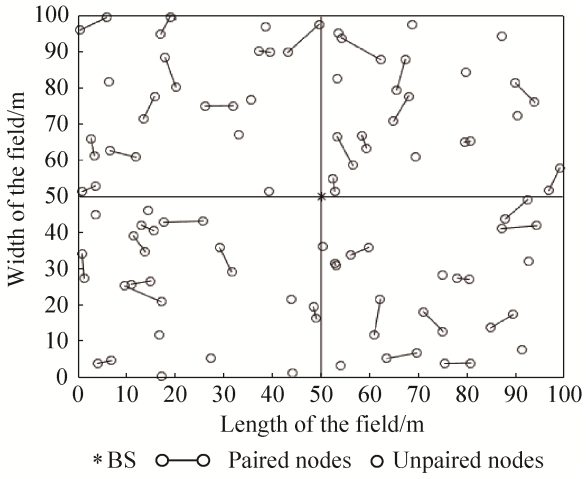

Fig. 2 One-hop neighbor node pairing in EESSTBRP

```
One-hop neighbor node pairing Algorithm
for each alive node in each region do
    node.status = Unpaired // Initially BS assigns all nodes as Unpaired
end for
Starting from the farthest node from the BS in each region
for a node $s_i$ find its close neighbor $s_j$ using greedy algorithm
    if ($s_i$.status = Unpaired) then
        if $d(s_i, s_j) \le Rs_i$ then
            $s_i$.status = Paired // update node $s_i$ status
            $s_j$.status = Paired // update node $s_j$ status
            Assign same Pair_ID to $s_i$ and $s_j$
            // proceed to find current node $s_j$'s close neighbor
        end if
        // otherwise $s_i$ remains permanently unpaired
        // proceed to find current node $s_j$'s close neighbor
    end if
    //$s_i$ is already paired. find current node $s_j$'s close neighbor
end for
```

Fig. 3 Pseudocode of one-hop neighbor node pairing in EESSTBRP

2.2 Sleep scheduling phase

In this phase, all the unpaired nodes are assigned an active status by the BS and remain in active mode throughout the rounds until they are dead. The paired nodes are considered to be sensing the same data, therefore to remove redundant data and save battery power, they switch between active and sleep modes during the rounds until they are dead as in Fig 4.

```
Paired nodes sleep scheduling Algorithm
Get P node pairs in each region of the network
for each pair do
    if ($s_i.E_{res} \ge 0.1*En$) then
        $s_i$.mode = Active
        $s_j$.mode = Sleep
    else if ($s_j.E_{res} \ge 0.1*En$)
        $s_i$.mode = Sleep
        $s_j$.mode = Active
    else                    // both nodes energy below $0.1*En$
        if ($s_i.E_{res} > s_j.E_{res}$) then
            $s_i$.mode = Active
            $s_j$.mode = Sleep
        else
            $s_i$.mode = Sleep
            $s_j$.mode = Active
        end if
    end if
end for
```

Fig. 4 Pseudocode of sleep scheduling in EESSTBRP

Using the *Pair_ID*, the BS identifies each node pair. The nodes in each pair are denoted as s_i and s_j, where s_j is the close neighbor to s_i as discovered during the one-hop neighbor node pairing. Initially, node s_i is assigned an active mode while node s_j switches to sleep mode. Node s_i remains active for a number of rounds until its residual energy, E_{res} is below 10% of its initial energy, *En*. At this point, node s_j switches to active mode and node s_i switches to sleep mode. Node s_j remains active for the next number of rounds until its residual energy is below 10% of its initial energy. At this point, for each of the remaining rounds, a node in the pair with highest residual energy is chosen as the active node while the other node switches to sleep mode.

2.3 Cluster head selection phase

In each round, the BS selects a cluster head (CH) in each region from the active nodes based on a weight value, *Q* of residual energy of the active nodes and distance from the BS. The active node, s_i with the highest weight ratio is selected.

$$Q = \frac{E_{res}(s_i)}{d(s_i, BS)} \tag{7}$$

$$d(s_i, BS) = \sqrt{(x_{si} - x_{BS})^2 + (y_{si} - y_{BS})^2} \tag{8}$$

2.4 Minimum spanning tree formation phase

In this phase, considering each region as a connected undirected graph, *G (V, E).* Where *V* is a set of vertices that represents the active nodes in each region and *E* is the set of the edges representing the links between the active nodes. In order to connect all the active nodes in *V* together with the minimal total weighting for their edges, the BS builds a minimum spanning tree in each region with the CH as the root using prim's algorithm as follows: Initially, for each region, the CH node is put in the tree. Next, in each iteration a minimum weighted edge is selected from an active node in the tree to an active node not in the tree, and that edge is added to the tree. The active node that has just been included in the tree will send its data through that edge, which represents a link of distance, *d*. This procedure is repeated until all active nodes are added to the tree as shown in Fig 5.

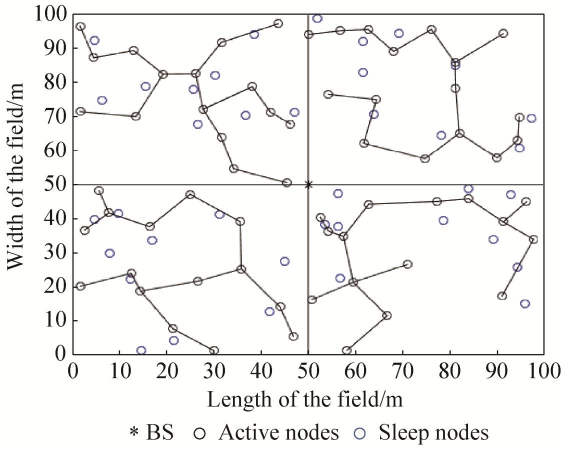

Fig. 5 Minimum spanning tree in EESSTBRP

2.5 Data transmission phase

The BS computes the routing information for each active node in each region. This information includes the parent node ID and a TDMA schedule for when each child node will send data to its parent node in its time slot. After receiving this information, each child node sends its sensed data and residual energy data to its parent node. The parent nodes receive this data and aggregate it together with their own sensed data as well as their residual energy data. This is done along the tree in each region until data is received by the CH nodes. The CH nodes then aggregate this data together with their own sensed data and residual energy data and then finally transmit it to the BS.

After this phase, the sleep scheduling phase and the phases that follow are repeated until all the nodes in the network are dead.

3 Simulation and analysis of results

A MATLAB simulation of EESSTBRP is done to evaluate its performance using simulation parameters in Tab. 1. For a fair comparison with PEGASIS, we deploy the BS at the center of the PEGASIS network and utilize the BS to construct the chain.

Tab. 1 Simulation parameters used

No.	Simulation Parameter	Values
1.	Simulation Area	100 m×100 m
2.	Network size	100 nodes
3.	$E_{elec}(E_{Tx}$ & $E_{Rx})$	50 nJ/bit
4.	E_{fs} (free space)	10 pJ /bit/m^2
5.	E_{amp} (Multipath fading)	0.0013 pJ/bit/m^4
6.	Initial Energy of nodes (*En*)	0.5J
7.	HELLO-bit packet size	30
8.	*K*- bit data packet size	4 000
9.	Simulation rounds	5 000
10.	Sensing range (*Rs*)	10 m

3.1 Network lifetime

The results of the simulation are as shown in Fig 6. In PEGASIS, the first node and last node die after 1 135 and 2 270 rounds respectively. In EESSTBRP the first node and last node die after 2 122 and 4 516 rounds respectively. Therefore, EESSTBRP performs 1.87 times and 1.98 times better than PEGASIS in analysis of when the first and last node die respectively.

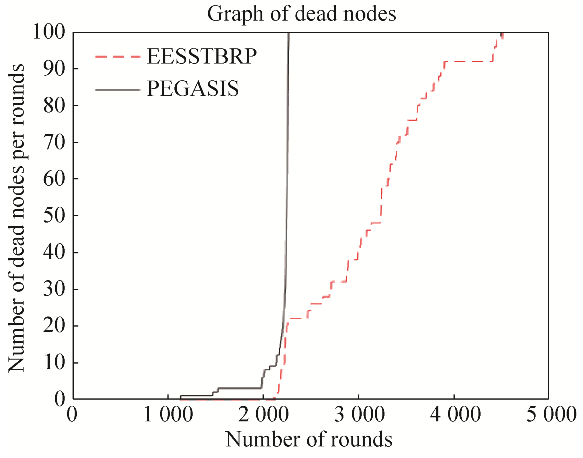

Fig. 6 Growth curve of dead nodes

3.2 Residual energy

Fig. 7 is the energy consumption of the two protocols. The results show that the energy consumption in the EESSTBRP network is less than that of the PEGASIS network and therefore has more residual energy per number of rounds in comparison to the PEGASIS network.

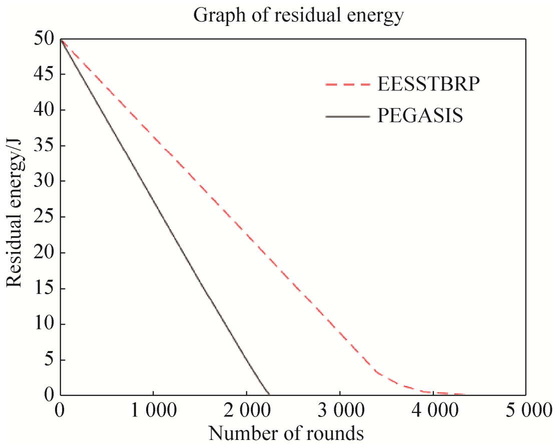

Fig. 7 Energy consumption

4 Conclusion

In this paper, we have proposed an energy efficient sleep-scheduled tree-based routing protocol to extend the lifetime of sensor nodes in the wireless sensor network. In the proposed routing scheme, battery power can be saved by switching off some nodes that sense the same data. Energy consumption due to nodes switching from one mode to another is minimized by ensuring that the paired nodes do not switch between the active and sleep modes in each round of communication thus maximizing lifetime of the sensor network. Selection of the CH role in each round is done based on residual energy and distance from base station thus improving energy efficiency and lifetime in the network. Further, routing using the minimum spanning tree minimizes energy consumption of nodes since the nodes send data to their nearest parent node. The MATLAB simulation showed that the proposed approach achieves a longer network lifetime in comparison to PEGASIS.

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