Power Save Protocol Using Chain Based Routing

Nguyen Thanh Tung[1], Nguyen Van Duc[2], Nguyen Hai Thanh[1],
Phan Cong Vinh[3], and Nguyen Dai Tho[4]

[1] International School, Vietnam National University
{tungnt,thanh.ishn}@isvnu.vn
[2] Hanoi University of Technology
ducnv-fet@mail.hut.edu.vn
[3] Nguyen Tat Thanh University
pcvinh@ntt.edu.vn
[4] University of Engineering and Technology,
Vietnam National University
nguyendaitho@vnu.edu.vn

Abstract. Sensor networks are deployed in numerous military and civil applications, such as remote target detection, weather monitoring, weather forecast, natural resource exploration and disaster management. Despite having many potential applications, wireless sensor networks still face a number of challenges due to their particular characteristics that other wireless networks, like cellular networks or mobile ad hoc networks do not have. The most difficult challenge of the design of wireless sensor networks is the limited energy resource of the battery of the sensors. This limited resource restricts the operational time that wireless sensor networks can function in their applications. Routing protocols play a major part in the energy efficiency of wireless sensor networks because data communication dissipates most of the energy resource of the networks. In many situations, a base station only needs a summary of the gathered information. For example, the base station might only require the maximum temperature of all sub-regions, each covered by a sensor or the average temperature of all sensors in the network. For similar types of application, data aggregation can be applied at all sensor nodes before the data is forwarded to the base station. The above discussions imply a new family of protocols called chain-based protocols. In the protocols, all sensor nodes sense and gather data in an energy efficient manner by cooperating with their closest neighbors. The gathering process can be done until an elected node calculates the final data and sends the data to the base station.

Keywords: Sensor, Routing, Chain based Routing, Linear Programming.

1 Introduction

Lindsey et al. [5] proposed one type of chain-based protocol called PEGASIS (Power-Efficient Gathering in Sensor Information Systems), which is near optimal for gathering data in sensor networks. PEGASIS forms a chain among sensor nodes so that each node will receive data from a close neighboring node and transmit data to

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another close neighbor. Gathered data moves from a sensor node to the nearest neighbor, is aggregated with the neighbor's data, and eventually reaches a determined Cluster-Head (CH) before finally being transmitted to the Base Station (BS). Fig. 1 illustrates the ideas of the PEGASIS protocol. In this round of data transmission, Node 3 is elected as the CH. Node 5 transmits data to Node 4, and Node 4 fuses the data with its own data and transmits the fused data to Node 3. Similarly, Node 1 transmits data to Node 2, and Node 2 transmits the fused data to Node 3. Finally, Node 3 fuses the data of the other nodes with its own data and transmits the final fused data to the base station. The data fusion function can be any function e.g. minima, maxima and average, depending on the specific applications as discussed in [1],[2],[3]. Nodes take turns equally to be the CH so that the energy spent by each node is balanced. In other words, each node becomes a CH once for every *n* rounds of data transmission, where *n* is the number of sensor nodes.

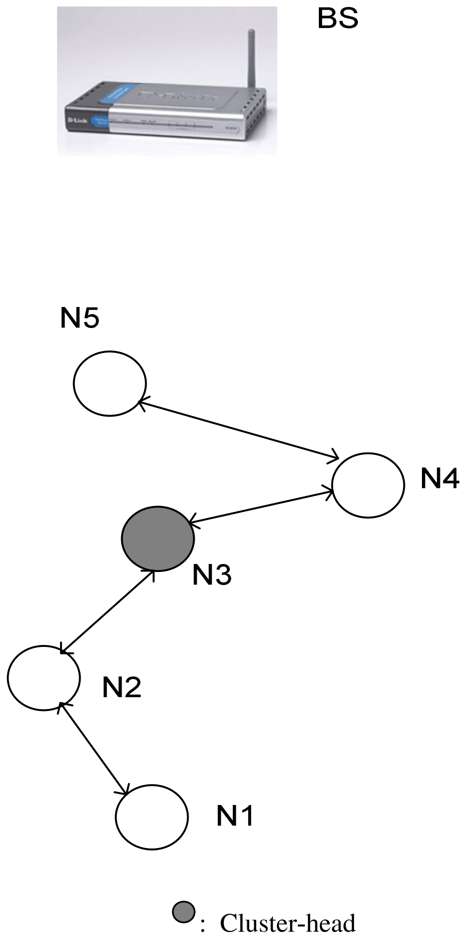

Fig. 1. A reconstructed chain from PEGASIS method

The authors in [5] showed that building a chain to minimize the energy consumption is similar to the traveling salesman problem [6], which is known to be NP-complete. They proposed a greedy algorithm starting from the furthest node from the base station until a near optimal chain is built as follows:

1) Add the node furthest from the base station to the chain

2) This node finds a closest node from it that is not already in the chain

(Closest Euclidean distance)

3) Repeat until all nodes are added to the chain.

Fig. 2 shows the formation of a chain with five sensor nodes. Node 1 connects to Node 2, Node 2 connects to Node 3, Node 3 connects to Node 4 and Node 4 connects to Node 5.

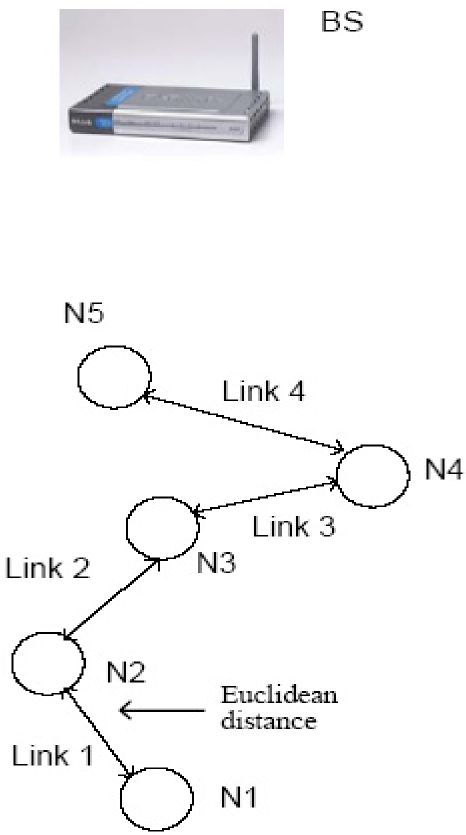

Fig. 2. Greedy algorithm to build a chain by PEGASIS method

In each round, a sensor node must be selected as the CH. Each sensor node receives data from its downstream neighbor, fuses with its own data to generate a single packet of the same length, and transmits the fused data to its upstream neighbor on the chain. This process is illustrated in Fig. 3 below. When Node 4 is selected as the CH, Node 3 fuses data with Node 5. Node 2 fuses its data with Node 1. Node 4 fuses its data with Node 2 and Node 3 and transmits the data to the base station.

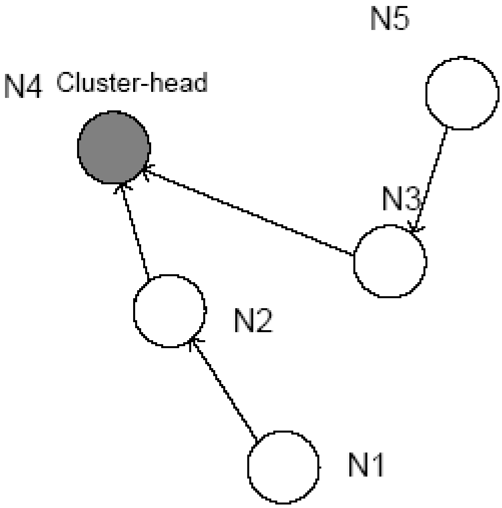

Fig. 3. Data moving from all sensor nodes to the CH node

2 Problem Formulation

In many applications, the data reporting of all sensor nodes is critical as in medical applications or in security applications. The above PEGASIS protocol tries to ensure that every node can become a CH equally. This is not appropriate for optimum system lifetime. Sensor nodes that are far away from the base station will consume more energy than closer nodes to send data to the base station. Also, nodes that have too little energy should not become CHs. As an equal selection of CHs will result in a reduced lifetime, a formulation to determine the CH pattern among all sensor nodes is presented below.

Let us define n to be the number of sensor nodes, and x_j to be the number of rounds node j becomes a CH. In chain-based routing, only one CH is selected each round. Therefore, there are n possible choices of CHs. The problem for the selection of the CHs is formulated as follows:

Maximize: $\sum_{j=1}^{n} x_j$

Subject to:

$$\sum_{j=1}^{n} c_j^i x_j \le E_i : \forall i \in [1...n] \qquad (1)$$

$$x_j \in Z^+ : \forall j \in [1...n]$$

,where c_j^i is the energy usage of Node i to send a unit of data in a round, when Node j becomes CH and E_i to be the initial energy storage of Node i

The above Linear Programming problem tries to maximize the total number of rounds of transmitting data by all sensor nodes under the battery-constraint of all sensor nodes. The energy coefficients c_j^i of each non CH node include the energy dissipation for the node to receive data from its downstream neighbor and to send the fused data to its upstream neighbor in the chain. The energy coefficients of each CH node in the formula include the energy dissipation for the node to receive data from its downstream neighbors and to send the fused data to the base station. The diagram in Fig. 4 shows that when Node 4 becomes a CH, c_4^2 includes the energy dissipation to receive data from Node 1 and to send the fused data to Node 4. c_4^4 includes the energy dissipation to receive data from Node 3 and Node 2 and to send the fused data to the base station.

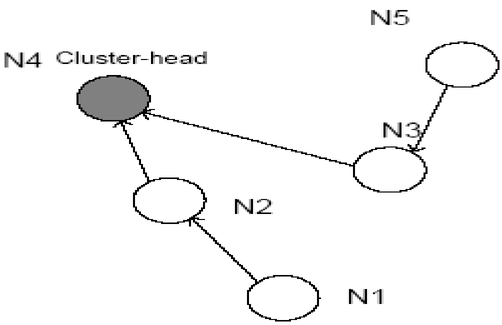

Fig. 4. Energy consumption coefficients of every sensor depends on the position of the CH

3 A New Heuristic Solution

Problem formulation (1) can be solved by Linear Programming solvers. These solvers are not always available and it is not easy to build these solvers inside sensors.

Therefore, the heuristic RE_chain algorithm is proposed. In the RE_chain algorithm, the CH positions are reallocated among the sensor nodes so that the minimum residual energy of all sensor nodes is maximized. The heuristic algorithm (RE_chain) is given as below:

RE_chain:

In every round of data transmission to the base station, select a sensor node as a leader for the chain in order to maximize the minimum residual energy of all sensor nodes after sending data for the round.

Given:

N : the number of sensor nodes indexed from 1 to N

s : A current CH solution

$f(s)$: The minimum residual energy of all nodes with solution s

s_0 : Best solution so far

RE_chain algorithm:

Initialization: $s_0 \leftarrow 0$

For (s from 1 to N)

$$\delta = f(s) - f(s_0)$$

If $\delta > 0$ **then** $s_0 = s$

Result: s_0 is the CH solution obtained from the RE_chain algorithm

4 Simulation Results

To evaluate the performance of RE_chain and compare the performance with that of PEGASIS and LEACH protocol [1], a number of simulators in Visual C++ were developed. The comparison between the system lifetime from Problem formulation (1) and that of RE_chain is also performed. In the first set of simulations, the performance of RE_chain is compared to the solution given by Formulation (1). In the simulations, 100 random 100-node sensor networks are generated. Each node begins with 1 J of energy. The network settings for the simulations in this section are given below. The energy model was used in [1],[3],[9],[10],[11].

Network size $(100m \times 100m)$
Base station $(50m, 300m)$
Number of sensor nodes 100 nodes
Data message size: 4000 bits
Broadcast message: 200 bits
Energy message: 20 bits
Position of sensor nodes: Uniform placed in the area
Energy model: $E_{elec} = 50*10^{-9}$ J, $\varepsilon_{fs} = 10*10^{-12}$ J/bit/m^2 and $\varepsilon_{mp} = 0.0013*10^{-12}$ J/bit/m^4

Fig. 5 shows the ratio of the number of rounds of RE_chain and the Linear Programming solution of Formulation (1). From the simulation result, it can be said that RE_chain performs within 1% of the Linear Programming solution.

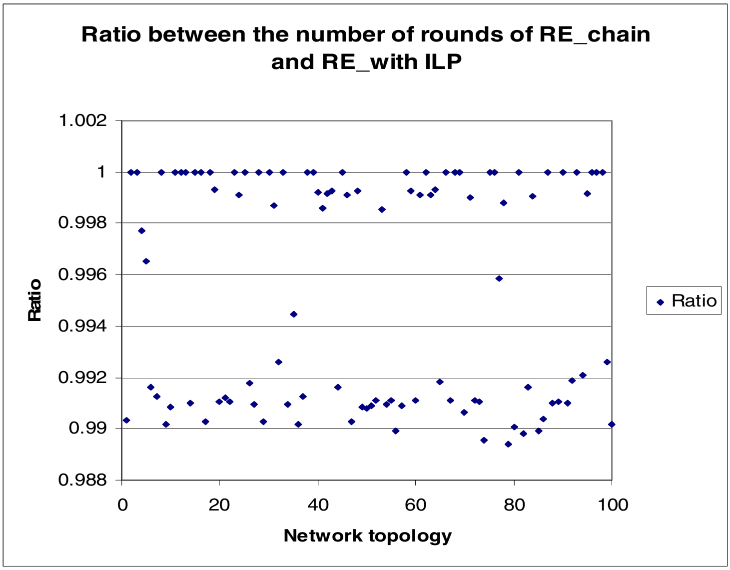

Fig. 5. Ratio of the number of rounds between RE_chain and RE_chain_with_ILP

It is also of interest to compare the performance of RE_chain, PEGASIS, and LEACH on the network topologies. On average, LEACH, PEGASIS, and RE_chain perform 602, 890, and 1305 rounds respectively.

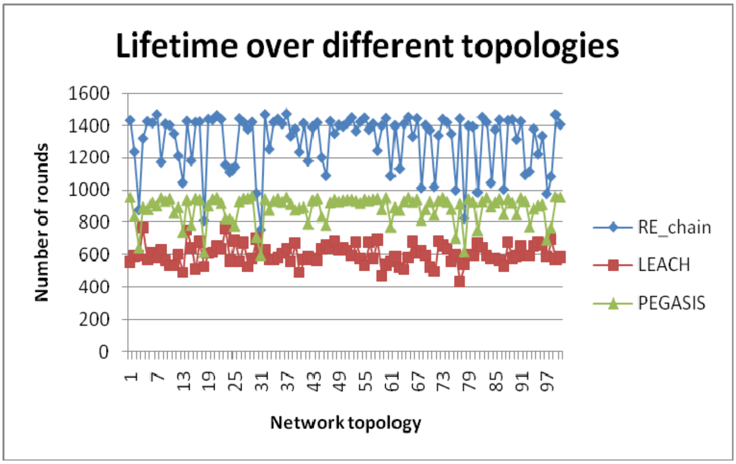

Fig. 6. Number of rounds over 100 random 100-node networks

Table 1. Results for Fig. 6

Protocol	PEGASIS	RE_chain	LEACH
Mean	890.3	1305.4	602.3
Variance	84.9	174.5	62.5
90 % confidence interval of the sample means	(876, 904)	(1276, 1335)	(592, 613)

5 Conclusion

This paper has focused on a new family of routing protocols for sensor networks: chain-based routing protocols. In chain-based routing, nodes form a chain connecting all nodes in the network. Data are gathered from all sensor nodes and move along the chain toward an elected sensor. The role of the elected node is rotated between all sensor nodes to increase the network lifetime. Chain-based routing exploits the data aggregation capability of sensor networks at maximum. When data are gathered from all sensor nodes, the data are aggregated with the data from their neighbors into a single message. The process is repeated until a single message is collected at the elected sensor node.

The previous chain-based routing (PEGASIS) selects the CH nodes uniformly among all sensor nodes. It is demonstrated in this chapter that the selection is a bad practice to ensure a good lifetime. Depending on the energy usage of each sensor to send data to its neighbors and to the base station, the sensor nodes should be elected as a leader differently. The paper has then proposed a method to optimize the selection of the CH among all sensor nodes using Linear Programming formulations. As it is not always practical to do the Linear Programming formulation, a simple heuristic method called RE_chain is proposed to calculate the selection. Simulations showed that RE_chain performs very closely to the Linear Programming formulation. The performance of RE_chain was then compared to that of LEACH, PEGASIS. This was shown that RE_chain improves the system lifetime significantly than that of PEGASIS. Also, it was observed that RE_chain performs about 3 times better than LEACH.

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