Maximizing the Lifetime of Wireless Sensor Networks with the Base Station Location

Nguyen Thanh Tung[1(✉)], Dinh Ha Ly[2], and Huynh Thi Thanh Binh[2]

[1] International School, Vietnam National University, Hanoi, Vietnam
tungnt@isvnu.vn
[2] Hanoi University of Science and Technology, Hanoi, Vietnam
greeny255@gmail.com, binhht@soict.hust.edu.vn

Abstract. Nowadays, wireless sensor networks (WSNs) have been increasingly applied in many different areas and fields. However, one major defect of WSNs is limited energy resources, which affects the network lifetime strongly. A wireless sensor network includes a sensor node set and a base station. The initial energy of each sensor node will be depleted gradually during data transmission to the base station either directly or through other sensor nodes, depending on the distance between the sending node and the receiving node. This paper considers specifying a location for the base station such that it can minimize the consumed energy of each sensor node in transmitting data to that base station, in other words, maximizing the network lifetime. We propose a nonlinear programming model for this optimal problem. Four methods, respectively named as the centroid, the smallest total distances, the smallest total squared distances and greedy method, for finding the base station location are also presented, experimented and compared to each other over 30 data sets that are created randomly. The experimental results show that a relevant location for the base station is essential.

Keywords: Base Station Location · Wireless Sensor Network · Routing · Non-Linear Programming

1 Introduction

Nowadays, with the considerable development of integrated circuit engineering, embedded systems and the strong power of network, it is inevitable for the birth of wireless sensor networks.

Wireless Sensor Network (WSN) is a network of sensor nodes in which network nodes are placed in such areas that can collect, exchange then send information to the base station through their sensor function, not links. By this way, it is possible to deploy WSN on almost all types of terrains simply. Hence, people can be aware of dangerous or hard to reach areas easily and frequently. Sensor nodes can collect information related to humidity, temperature, concentration of pesticides, noise, etc; which makes WSN applicable to many fields such as environment, heath, military, industry, agriculture….

Although the benefit of WSNs is extremely great, its one major defect is limited energy resources. When energy source of a sensor node runs out, this node dies,

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which means it can no longer collect, exchange as well as send information to the base station. And the WSN, therefore, will not be able to complete its mission.

In this paper, we are interested in how to use sensor nodes' energy effectively, in other words, to maximize the lifetime of WSNs. We consider the model in which all sensor nodes in the network are responsible for sending data to the base station in every specified period. When a sensor node sends data, its consumed energy depends on the distance between it and the node which receives data. In this research, we suppose that energy for transmitting a data unit is directly proportional to the square of distance between two nodes.

In [1, 2, 3, 6, 7, 12], the base station is placed at a random location. However, the fact shows that the location needs to be optimized. This paper proposes four methods that are the centroid, the smallest total distances, the smallest total squared distances and the greedy method to specify this optimal location. Also, we propose a nonlinear programming model for optimizing the WSN lifetime and use this model to evaluate our proposed methods over 30 randomly created data sets . The experimental results show that a relevant location for the base station is essential, which proves our correct research way.

The rest of this paper is organized as follows: Section 2 describes the related works. Mathematical model for this problem is introduced in section 3. Four methods for specifying the base station location is showed in section 4. Section 5 gives our experiments as well as computational and comparative results. The paper concludes with discussions and future works in section 6.

2 Related Works

Until now, the problem of maximizing the lifetime of WSNs has received a huge interest of the researchers. According to [1], there have two different approaches for maximizing the network lifetime. One is the indirect approach aiming to minimize energy consumption, while the other one directly aims to maximize network lifetime.

With the indirect approach, the authors [2] gave a method to calculate energy consumption in WSNs depending on the number of information packets sent or the number of nodes. Then they proposed the optimal transmission range between nodes to minimize total amount of consumed energy. With this method, the total energy consumption is reduced by 15% to 38%.

Cheng et al. formulated a constrained multivariable nonlinear programming problem to specify both the locations of the sensor nodes and data transmission patterns [3]. The authors proposed a greedy placement scheme in which all nodes run out of energy at the same time. The greed of this scheme is that each node tries to take the best advantage of its energy resource, prolonging the network lifetime. They reason that node i should not directly send data to node j if $j \geq i + 2$ because communication over long links is not desirable. Their greedy scheme offered an optimal placement strategies that is more efficient than a commonly used uniform placement scheme.

In [12] proposed a network model for heterogeneous networks, a set of Ns sensors is deployed in a region in order to monitor some physical phenomenon. The complete set of sensors that has been deployed can be referred as $S=\{s1......sN\}$. Sensor i

generates traffic at a rate of *ri* bps. All of the data that is generated must eventually reach a single data sink, labeled *s0*. Let $q_{i,j}$ be traffic on the link *(i,j)* during the time *T*. The network scenario parameters also include the traffic generation rate *ri* for each sensor. The power model in [6,7,10,12,13], is used, where the amount of energy to transmit a bit can be represented as:

The total transmission energy of a message of *k* bits in sensor networks is calculated by:

$$E_t = E_{elec} + \varepsilon_{FS} d^2$$

and the reception energy is calculated by:

$$E_r = E_{elec}$$

where E_{elec} represents the electronics energy, ε_{FS} is determined by the transmitter amplifier's efficiency and the channel conditions, *d* represents the distance over which data is being communicated.

Maximize: *T*

Subject to:

$$\sum_{j=1}^{N} q_{j,i} + r_i T = \sum_{j=0}^{N} q_{i,j} : \forall i \in [1...N] \tag{1}$$

$$\sum_{j=0}^{N} (E_{elec} + \varepsilon_{FS} d^2) q_{i,j} + \sum_{j=1}^{N} E_{elec} q_{j,i} <= E_i : \forall i \in [1...N] \tag{2}$$

$$q_{i,j} >= 0 : \forall i, j \in [1...n] \tag{3}$$

3 Problem Formulation of Maximizing the Lifetime of Wireless Sensor Networks with the Base Station Location

A sensor network is modeled as a complete undirected graph *G = (V, L)* where *V* is the set of nodes including the base station (denoted as node *0*) and *L* be the set of links between the nodes. The size of *V* is *N*. The link between node *i* and node *j* shows that node *i* can send data to node *j* and vice versa. Each node *i* has the initial battery energy of E_i. Let Q_i be the amount of traffic generated or sank at node *i*. Let d_{ij} be the distance between node *i* and node *j*. Let *T* be the time until the first sensor node runs out of energy. Let q_{ij} be the traffic on the link $L_{(ij)}$ during the time *T*. The problem of maximizing the lifetime of the wireless sensor networks with the base station is formulated as follows:

Maximize: T

Subject to:

$$\sum_{j=1}^{N} q_{ji} + QT = \sum_{j=0}^{N} q_{ij} : \forall i \in [1...N] \quad (4)$$

$$\sum_{j=1}^{N} q_{ij} d_{ij}^2 + q_{i0}[(x_i - x_0)^2 + (y_i - y_0)^2] <= E_i : \forall i \in [1...N] \quad (5)$$

$$\sum_{i=1}^{N} q_{i0} = Q_0 \quad (6)$$

$$q_{ij} >= 0 : \forall i, j \in [0...N] \quad (7)$$

$$x_0, y_0, T : Variable$$

In which, (x_i, y_i) is coordinate of node i in the 2-dimensional space.

4 Four Methods for Specifying the Base Station Location

To maximizing the lifetime of WSNs, the base station location not only is close, but also balances distances with as many sensor nodes as possible. This guarantees that sensor nodes do not consume too much energy in transmitting data to the base station and no sensor node depletes its energy much faster than other nodes. The center of network seems to be in accord with this requirement. However, there are many definitions for the center of network, each definition gives different locations. So this paper proposes four methods corresponding to four different "center" definitions to specify the center of network that is also the base station location.

These four methods are named respectively as the centroid, the smallest total distances, the smallest total squared distances and the greedy methods. After this base station location is determined, the model in section 3 becomes a linear optimal one. By using a tool to find the lifetime of WSN, we can evaluate quality of this base station location as well as that of these methods. Four methods are as follows:

The Centroid Method: defines the base station location as the centroid of all sensor nodes. This location is calculated by (8).

$$x_0 = \frac{\sum_{i=1}^{N} x_i}{N-1}, y_0 = \frac{\sum_{i=1}^{N} y_i}{N-1} \quad (8)$$

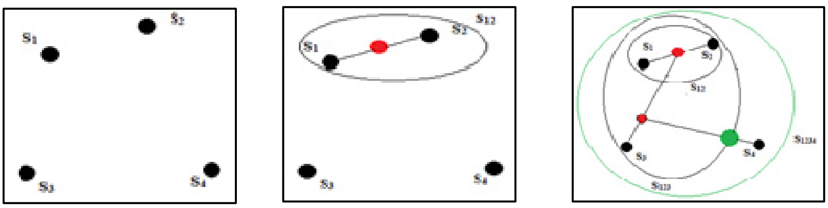
The Smallest Total Distances Method: the base station location is a point such that the Euclidean distance summation from it to all sensor nodes is the smallest one. This point satisfies (9). With this definition, easily seen, the base station location should be a point in the convex hull of all sensor nodes. However, for the sake of simplicity, this location is found in the smallest rectangle surrounding all sensor nodes.

$$Min : \sum_{i=1}^{N} \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \tag{9}$$

The Smallest Total Squared Distances Method: it is similar to the smallest total distances one, but the base station location has to satisfy that the sum squared distances from it to all sensor nodes is the smallest.

$$Min : \sum_{i=1}^{N} (x_i - x_0)^2 + (y_i - y_0)^2 \tag{10}$$

The Greedy Method: defines a sensor set includes sensor nodes and a delegate center. If the set has only one sensor node, its delegate center is this own sensor node. Also, we define the distance between two sensor sets is the distance between their two delegate centers. The main idea of this method is that starting with one-sensor-node sets (Fig 1(a)), we merge two sets having the smallest distance (sensor node set S1 and S2 in Fig 1(a)). A new delegate center for the merged set (the red node in Fig 1(b)) is specified as follows: this center is on the line segment connecting two old delegate centers and splits this line into two segments with proportional by *p*. The sensor sets is merged until only one set remains. The delegate center of this last set is the base station location (The green node in Fig 1(c)).



(a) (b) (c)

Fig. 1. Illustration of the greedy method

5 Experimental Results

5.1 Problem Instances

In our experiments, we created 30 random instances denoted as *TPk* in which *k* (*k = 1, 2,.., 30*) shows ordinal number of a instance. Each instance consists of *l* lines. Each line has two numbers representing coordinate of a sensor node in the 2-dimensional space.

5.2 System Setting

The parameters in our experiments were set as follows:

Table 1. The experiment parameters

Parameter	Value
The network size	100m x 100m
Number of sensor nodes - *l*	30
Initial energy of each node - *E*	1 J
Ratio *p* in method 4	$\frac{\sqrt{cx}}{\sqrt{cy}}$ with *cx*, *cy* is the number of sensor nodes in two old sensor sets.
Energy model	$E_{elec} = 50 * 10^{-9}$ J $\varepsilon_{fs} = 10 * 10^{-12}$ J/bit/m^2 $\varepsilon_{mp} = 0.0013 * 10^{-12}$ J/bit/m^4

5.3 Computational Results

Table 2 presents the base station location found by four methods in the section 4 for 30 random instances. The results of the centroid, the smallest total distances, the smallest total squared distances and the greedy method is in BS1, BS2, BS3 and BS4 column respectively. Through this table, we can see that the centroid and the smallest total square distances method gave extremely close locations over all instances. The difference between locations found by these four methods for each instance is inconsiderable.

The lifetime of 30 WSNs corresponding to 30 instances is showed in the table 3. These lifetime were found by using the tool with the found base station locations in the table 2. The maximum lifetime of each instance is traced with green.

The greedy method gave the best lifetime over 20 instances, the best lifetime with the base station location found by the centroid method is over 8 instances, by the smallest total squared distances method is over 7 instances and by the smallest total distances method is over 5 instances.

The lifetime with the base station location of the centroid method and the smallest total squared distances method is about the same over all data sets, which can be explained by the relatively same coordinate of these base station locations.

Despite giving the second best base station location, the centroid is the simplest method which is suitable to real-time or limited computing systems.

The difference among the network lifetimes corresponding to the base station location gave by four methods over all instances shows that the location for the base station should be optimized as mentioned in the section 1.

Table 2. The base station location found by four methods for 30 instances

Ins.	BS1 (x-y)	BS2 (x-y)	BS3 (x-y)	BS4 (x-y)	Ins.	BS1 (x-y)	BS2 (x-y)	BS3 (x-y)	BS4 (x-y)
TP1	55.2-39.9	54-37	55-40	53.1-50.5	TP16	38.3-59.9	36-64	38-60	38.5-54.2
TP2	39.9-55.3	36-60	40-55	40.6-54.8	TP17	59.9-38.5	62-35	60-39	58.1-42.3
TP3	55.3-42.6	55-41	55-43	52.6-53.0	TP18	38.5-61.2	35-66	39-61	38.9-55.0
TP4	42.6-56.2	40-62	43-56	42.1-55.1	TP19	61.2-40.5	64-37	61-41	52.1-40.2
TP5	56.2-42.3	57-39	56-42	52.1-53.4	TP20	40.5-59.6	36-64	41-60	47.0-58.4
TP6	42.3-56.4	39-61	42-56	41.8-55.0	TP21	59.6-40.3	62-37	60-40	57.6-43.4
TP7	56.4-42.9	58-40	56-43	53.3-54.6	TP22	40.3-58.2	36-64	40-58	47.0-57.7
TP8	42.9-56.8	39-63	43-57	44.7-53.6	TP23	58.2-39.0	60-34	58-39	56.8-43.1
TP9	56.8-41.3	59-36	57-41	54.1-53.7	TP24	39.0-55.9	35-63	39-56	45.9-56.3
TP10	41.3-58.4	36-64	41-58	45.9-54.5	TP25	55.9-39.4	58-35	56-39	53.9-44.3
TP11	58.4-42.0	62-38	58-42	54.5-53.5	TP26	39.4-54.6	36-59	39-55	46.2-55.0
TP12	42.0-58.7	36-64	42-59	46.1-54.9	TP27	54.6-41.5	56-38	55-42	53.6-45.5
TP13	58.7-39.9	61-36	59-40	57.4-43.3	TP28	41.5-53.2	39-55	42-53	47.3-54.0
TP14	39.9-59.9	36-65	40-60	46.1-48.9	TP29	53.2-39.4	54-35	53-39	53.9-45.6
TP15	59.9-38.3	62-35	60-38	58.1-41.9	TP30	39.4-50.5	37-51	39-51	45.9-52.6

Table 3. The lifetime of WSNs with the corresponding base station locations in the table 2

Ins.	BS1	BS2	BS3	BS4	Ins.	BS1	BS2	BS3	BS4
TP1	870	811	867	890	TP16	762	739	761	812
TP2	809	652	820	836	TP17	907	907	907	907
TP3	867	845	866	865	TP18	746	726	747	793
TP4	838	885	837	829	TP19	893	870	894	907
TP5	878	839	869	877	TP20	751	695	750	786
TP6	822	832	815	805	TP21	1020	935	1003	1130
TP7	931	926	925	906	TP22	744	682	745	794
TP8	739	706	738	746	TP23	1056	943	1065	1124
TP9	941	910	948	907	TP24	695	587	694	746
TP10	736	700	736	738	TP25	1115	997	1116	1010
TP11	1044	1041	1044	971	TP26	843	741	838	893
TP12	777	722	777	791	TP27	1040	1048	1038	977
TP13	1171	1160	1171	1171	TP28	838	799	845	862
TP14	762	739	762	797	TP29	988	962	988	952
TP15	907	907	907	907	TP30	817	789	810	861

6 Conclusion

In this paper, we proposed a nonlinear programming model for maximizing the lifetime of wireless sensor networks with the base station location. We presented four methods that are the centroid, the smallest total distances, the smallest total squared distances and the greedy method for finding the base station location. These four methods were experimented on 30 random data sets. With the found base station locations, specific lifetime of WSNs were calculated by our model and showed that a relevant location for the base station should be essential.

In the future, we will find a method that provides the best solution in all random topologies tested.

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