

Research Article

Lifetime Optimization of a Multiple Sink Wireless Sensor Network through Energy Balancing

Tapan Kumar Jain, Davinder Singh Saini, and Sunil Vidya Bhooshan

Department of Electronics and Communication Engineering, Jaypee University of Information Technology, Waknaghat, Solan 173215, India

Correspondence should be addressed to Tapan Kumar Jain; tapan.jain@juit.ac.in

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The wireless sensor network consists of small limited energy sensors which are connected to one or more sinks. The maximum energy consumption takes place in communicating the data from the nodes to the sink. Multiple sink WSN has an edge over the single sink WSN where very less energy is utilized in sending the data to the sink, as the number of hops is reduced. If the energy consumed by a node is balanced between the other nodes, the lifetime of the network is considerably increased. The network lifetime optimization is achieved by restructuring the network by modifying the neighbor nodes of a sink. Only those nodes are connected to a sink which makes the total energy of the sink less than the threshold. This energy balancing through network restructuring optimizes the network lifetime. This paper depicts this fact through simulations done in MATLAB.

1. Introduction

A wireless sensor network (WSN) consists of small low energy sensing nodes capable of sensing a phenomenon and sending the data to the sink. The basic aim while structuring a WSN is to minimize the energy consumption and maximize the network lifetime. In a single sink WSN, the nodes need to send the data through multiple hops. In a large WSN, it becomes quite inefficient in terms of power consumption while gathering all information in a single sink [1]. Maximum energy consumption takes place in communicating the data from the nodes to the sink [2, 3]. To minimize the energy consumption while sending the data to the sink, multiple sinks are used. As there are multiple sinks, the distance from the node to the sink reduces; thus, there is no need of multiple hops. Multiple sinks reduce the distance the sensed data needs to travel and hence correspondingly reduce the energy consumption considerably [4]. Another disadvantage of a single sink WSN is that of energy imbalance between the nodes close to the sink and the ones which are far off [5]. The network is restructured by modifying the number of nodes connected to a sink. The current research work proposes an algorithm for network restructuring in a multiple sink

WSN so as to reduce the energy consumption and increase the network lifetime. This energy balancing through network restructuring optimizes the network lifetime. The number of not connected nodes are also quite less. The implementation is done in MATLAB. The implementation results prove the aforesaid statements.

2. Related Work

In a WSN, the fundamental question is to have the data routed over single hop or multiple hops. This question is answered by considering the answer to the question that the data needs to be sent over a longer or a shorter hop. Short-hop routing leads to reduced energy consumption and higher signal-to-interference ratios [6]. The less but longer hops lead to more energy consumption but less signal to interference ratio (SIR). Research paper [7] has proved that single-hop transmission is more efficient, when power consumption of real wireless sensor node's transceivers is taken into account.

So, this leads to four types of networks:

- (1) single hop single sink routing (SH-SS),
- (2) single hop multiple sink routing (SH-MS),

- (3) multiple hop single sink routing (MH-SS),
- (4) Multiple hop multiple sink routing (MH-MS).

The first scenario is the most elementary one with direct transmission. The LEACH protocol, which is better than the direct transmission, deals with single hop single sink clustering protocol [8].

A lot of research is done for the third scenario [9–11]. The modification of LEACH protocol is having multiple hops instead of single hop [9]. Reference [10] compares the single and multiple hop routing.

In [3], a multihop protocol spends most of its energy for relaying data packets so the concept of multihop multisink WSN is discussed. The concept of particle swarm optimization is used.

The current research paper deals with the second scenario, that is, single hop multiple sink. The biggest disadvantage of single sink is that certain sensors near the sink or on critical paths consume energy much faster than other nodes [12]. Thus the current work uses the advantage of having multiple sinks. Multiple sinks ensure shorter hops and thus the 18 advantages as discussed in the paper [6] are also achieved. Multiple hops are generally used to reduce the hop distance [13]. But if multiple sinks are used, the hop distance automatically reduces. Thus, the research deals with single hop and thus avoids the drawbacks of having multiple hops.

Network lifetime (NL) is a critical metric in the design of energy-constrained WSN [14]. The basic aim of the researchers is to minimize the energy consumption and at the same time increase the network lifetime. The authors in the paper [15, 16] deal with mobile multiple sinks. Data dissemination to multiple mobile sinks consumes a lot of energy [17]. Many papers [3, 15] have concentrated on positioning of the sink to have optimal energy consumption. The current research work talks about the random deployment of the sink thus saving power in determining the position of the sink. Then the network is restructured to have balanced energy consumption amongst all the sinks.

Table 1 summarizes the related work done in the field of single/multiple hops, single/multiple sinks, and moving/stationary nodes.

Network restructuring is changing the neighbor nodes connected to a sink depending upon the energy consumption by that sink.

In the current research work the number of sensors connected to any sink is changed if the energy consumption by the sink is more than the threshold. To have balanced energy consumption amongst all the nodes, the entire network is restructured.

The rest of the paper is organized in sections. The next section describes the proposed algorithm and its pseudocode. Section 4 deals with the simulation results. Section 5 concludes and gives the outline for the future work.

3. Proposed Algorithm

The proposed work concentrates on multiple sink single hop routing. The nodes and the sinks are randomly deployed. At the first instance the nodes are connected to a sink depending

upon their distance and the transmission energy. A node gets connected to a sink/s if its distance from the sink/s is less than the transmitting range. In this way all the nodes are connected to one or many sinks. There may be some nodes which are not connected to any of the sinks as they are deployed quite far from the network and are not within the transmission range of any sink. Table 2 depicts this fact. In the next phase network restructuring is done. The energy consumed by every sink is calculated and the sink with maximum energy consumption is found out. The unique nodes connected to this sink are traced. A unique node is one which is connected to only that sink. All the other connected nodes apart from the unique nodes are then found out. Such nodes are then connected to other sinks (within the transmission range), keeping in mind that the new energy consumption of that sinks does not cross the threshold. In this way the energy consumption of the sink, which was earlier consuming maximum energy, is reduced. This process is repeated for all the sinks in the increasing order of their energy consumptions. The end result is a network which now consumes less energy overall.

3.1. System Model and Assumptions

- (1) Sinks are randomly deployed and then they are fixed. Since random distribution is used, the complexity in determining the position of the sink is removed.
- (2) The nodes after random deployment are fixed.
- (3) The density of nodes deployed is high such that the data from a node reaches a sink in single hop.
- (4) The network is heterogeneous. The sinks have more power than the sensing nodes. The sinks have additional computational capacity as well.

3.2. Pseudocode

- (1) The sensor nodes and the sinks are randomly deployed and after the deployment the nodes and sinks are stationary. Combination of sink and sensor nodes will make the network heterogeneous.
- (2) N is the set of p nodes deployed in the area to be sensed in the given network:

$$N = \{n_1, n_2, n_3, \dots, n_p\}. \quad (1)$$

- (3) S is the set of q sinks deployed in the area to be sensed in the given network:

$$S = \{S_1, S_2, S_3, \dots, S_q\}. \quad (2)$$

- (4) Calculate the Euclidean distance from each sink to every node. DS_i is the set of distances of all the nodes from the i th sink:

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$i = \text{sink ID} = 1, 2, \dots, q, \quad j = \text{node ID} = 1, 2, \dots, p; \quad (3)$$

$$DS_i = \{D_{i1}, D_{i2}, D_{i3}, \dots, D_{ip}\}.$$

TABLE 1: Related work in multiple sinks in WSN.

Authors (year) papers	Hops	Sinks	Mobility of sink	Sink positioning	Network restructuring
Singh et al., 2014 [17]	Multiple	Multiple	Yes	No	No
Lee et al., 2009 [16]	Multiple	Multiple	Yes	Yes	No
Jain et al., 2014 [4]	Single	Multiple	No	Yes	No
Shah-Mansouri et al., 2009 [1]	Single	Multiple	Yes	Yes	No
Jain, 2012 [18]	Multiple	Single	No	Yes	No
Heinzelman et al., 2000 [8]	Single	Single	No	No	No
Farooq et al., 2010 [9], Koutsopoulos and Stanczak, 2012 [10], Li, 2005 [11], Fedor and Collier, 2007 [13]	Multiple	Single	No	No	No
Dandekar and Deshmukh, 2013 [3]	Multiple	Multiple	No	No	No

TABLE 2: Simulations parameters values.

Notation	Meaning
N	50, 100
E_0	Initial node energy (1 J)
E_{\max}	Max energy consumed by the sink
n_i	Node ID of i th node
A	(0, 0) to (500, 500) = 250000 m ²
R_s	Point sensor
R_t	150 m
E_r	$E_0 - E_{\text{processing}} - E_{DA} - E_{\text{sensing}}$
E_{th}	0.5 J initially till it reaches 0.1 J (changes after iterations)
S	10, number of sinks

So it will form a $[q, p]$ order distance matrix (D) which will contain the distances of all the sinks from all the nodes. The distance between the nodes is calculated using a method based on RSSI [19].

- (5) The threshold energy of the sink is E_0 .
- (6) The transmission range of a node is T_x .
- (7) The neighboring nodes of every sink are calculated based on the transmitting range. Nb_i is the set of all the neighboring nodes of i th sink (S_i):
- $$Nb_i \subseteq N, \quad \text{where } \{Nb_i \mid D_{ij} < T_x \in j, j \in N\}. \quad (4)$$

- (8) A new connection matrix (C) is formed based on D . A flag is set for every element where the distance from node to sink is less than the transmission range T_x . Thus C is in the binary form.
- (9) The energy consumed by i th sink E_i is calculated by

$$E_i = k \sum_{j=1}^{|Nb_i|} D_{ij}^2, \quad (5)$$

where $|Nb_i|$ is the total number of neighbor nodes of i th sink (S_i) and D_{ij} is the distance of i th sink from

the j th node where $n_j \in Nb_i$, and k is the constant for first order radio energy model [8].

- (10) Calculate the $E_{\max} = \text{maximum}(E_i)$, where $i = 1$ to q , and find the maximum energy consumed by any sink S_i .

- (11) If ($E_0 > E_{\max}$),

{

no need to optimize the network
iteration = 0;
set the E_0 below the E_{\max}
repeat step (10)

}

- (12) else

- (a) Calculate the unique nodes connected to a sink. A unique node to a sink is the one which is not connected to any other sink.

U_i is the set of unique nodes for S_i

$U_i \in Nb_i$

$U_i = \{n_1, n_2, n_3, \dots, n_i\} \in Nb_i \ \& \notin Nb_j$ Where $j = 1, 2, 3, \dots, q$ and $i \neq j$

Based on the above step and (7) we can easily calculate the nodes, having connectivity with more than one sink. MC_i is the multiple connecting nodes set having the connection with multiple sinks.

- (b) MC_i nodes of the i th sink are arranged into the descending order of the distance from the i th sink.

- (c) Select the nodes having the minimum distance from the i th sink and disconnect the connection of remaining nodes those are far from the i th sink, and update the overall connection matrix C based on the distance matrix D .

- (13) Repeat the steps (9)–(12) by recalculating the sink energy with modified C . The iteration count is also

TABLE 3: Not connected nodes.

Sinks	Not connected	E_{max}	E_{min}	E_{avg}	Max nodes connected to single sink
5	30	0.312	0.173	0.24	28
6	28	0.331	0.139	0.23	30
7	22	0.359	0.152	0.244	31
8	16	0.371	0.114	0.239	31
9	14	0.334	0.121	0.227	30
10	11	0.362	0.103	0.233	32
11	10	0.36	0.1	0.231	31
12	9	0.386	0.11	0.236	32
13	10	0.363	0.101	0.23	30
14	9	0.368	0.104	0.226	31
15	8	0.391	0.093	0.226	32

TABLE 4: After network restructuring.

Sinks	E_{max}	E_{min}	E_{avg}	Max connected node
5	0.24	0.173	0.195	15
6	0.23	0.139	0.193	15
7	0.244	0.152	0.192	10
8	0.247	0.114	0.211	12
9	0.288	0.121	0.21	11
10	0.274	0.103	0.2	12
11	0.245	0.1	0.197	10
12	0.245	0.11	0.196	8
13	0.26	0.101	0.194	7
14	0.24	0.104	0.198	6
15	0.242	0.093	0.21	7

TABLE 5

Sinks	Not connected	E_{max}	E_{min}	E_{avg}	Max nodes connected to single sink
10	11	0.362	0.103	0.233	32

increased. The steps are repeated until E_{max} becomes constant.

- (14) Now the network is optimized and the routing is started by the nodes. The lifetime of the network is calculated by counting the number of rounds done by the network before the first node dies out.

4. Simulation Results

The simulation of the abovementioned pseudocode was performed in MATLAB. The simulation parameters are mentioned in Table 2.

The numbers of nodes are not connected to any sink as the number of sinks that increases in the network are depicted in Table 3. In the proposed work we have considered the restructuring energy in terms of processing energy ($E_{processing}$). In the restructuring only the node connection

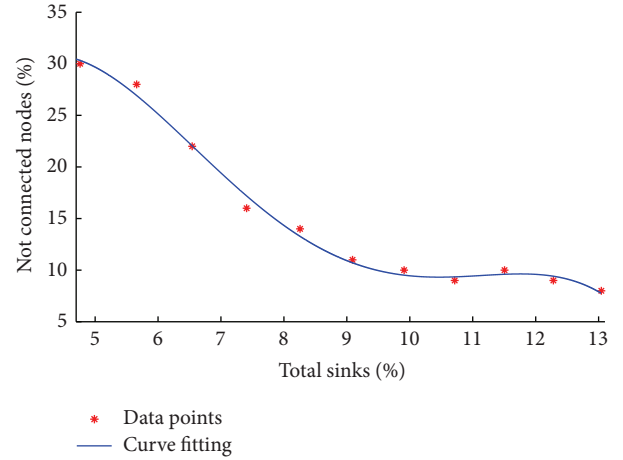


FIGURE 1: Node connected versus total sinks.

changes with one sink to other sinks to reduce the load of the sink and decrease the delay.

It is apparent from Table 3 that as we increase the sinks, the number of not connected nodes decreases. But after a certain point of time, the not-connected nodes more or less remain the same. Since the sinks and the nodes are randomly deployed, and the nodes are connected to the sink with a single hop, there are not connected nodes because of large transmission energy required outside the transmission range R_t ($E \propto d^4$) [8]. If we would have deployed the sinks manually, the number of not-connected nodes would have reduced considerably. The optimal number of sinks also depends upon the network area to be covered by the sinks.

Figure 1 depicts the plot of total percentage of sinks versus percentage of not-connected nodes. With the help of curve fitting tool of the 4th order polynomial, the suitable value is 0.12 sink/nodes. This proves that the optimal number of sinks is 12 for 100 nodes.

Now, the network restructuring algorithm mentioned in the Section 4 is applied to the data as depicted in Table 3.

Table 4 proves that, after restructuring, the network consumes less energy. The number of connected nodes changes as a result of which the total energy consumption by each sink reduces. As a result the total energy consumption of the network reduces considerably, thus increasing the network lifetime. The E_{min} remains the same as only the E_{max} is reduced. Since the E_{max} is decreased, the E_{avg} is automatically decreased. The maximum number of nodes connected to a sink also reduces. Consider the scenario of no of sinks = 10. In the initial phase, just after the deployment the parameters are as in Table 5.

After applying the algorithm, that is, after energy balancing through network restructuring, the values of the parameters change as depicted in the Table 6.

The E_{max} has changed from 0.362 to 0.274. Now, we consider one more scenario of changing the number of sensing nodes. The observations are depicted in Table 7 and Figure 2.

Thus it proves that the proposed algorithm is quite effective for multiple sink, single hop WSN. After the network

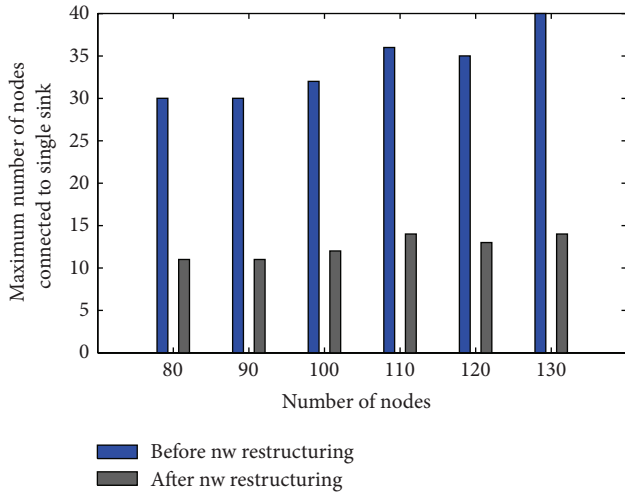


FIGURE 2: Maximum node connected to single sink.

TABLE 6

Sinks	Not connected	E_{max}	E_{min}	E_{avg}	Max nodes connected to single sink
10	11	0.274	0.103	0.2	12

TABLE 7: Maximum nodes connected to single sink.

No. of nodes	Maximum number of nodes connected to a single sink	
	Before the restructuring	After the restructuring
80	30	11
90	30	11
100	32	12
110	36	14
120	35	13
130	40	14

restructuring, the maximum number of nodes connected to a sink reduces considerably. As a result of this energy balancing, the network lifetime is increased and the energy consumption is reduced.

5. Conclusion and Future Work

The proposed work performs network lifetime optimization through energy balancing in a multiple sink single hop WSN. The network restructuring balances the energy amongst the sinks, thereby increasing the network lifetime. In the proposed algorithm we have considered the network lifetime with respect to the maximum and average energy consumption. The more the energy consumed, the less the network lifetime. The proposed restructuring algorithm reduces the maximum nodes connected to a sink. As a result the total energy consumed by the sink connected to the maximum nodes also decreases further resulting in increasing the total network lifetime. The implementation results shown in

MATLAB prove that network restructuring is beneficial in reducing the maximum and average energy of the sinks. The optimal number of sinks is also calculated using fourth order polynomial. The number of iterations used for simulation is 100. In 100 iterations the value of average energy (mean) is 0.2329 J and the standard deviation of mean is 0.0061 J. Since the standard deviation is very small so this iteration count is statistically valid.

In the future the authors wish to consider the scenario of a mobile sinks WSN. In this case there would be single hop routing with the sink moving randomly. This involves complexity of finding out the position of the sinks. The authors also wish to have sinks deployed at fixed positions in the initial phase instead of random deployment. And then finally compare the results obtained in different scenarios with multiple sink moving/stationary with and without initial sink positioning.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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