Multiple Mobile Sinks Positioning in Wireless Sensor Networks for Buildings

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Abstract

Real deployment of wireless sensor networks inside buildings is a very challenging. In fact, in such networks, a large number of small sensor devices suffer from limited energy supply. These sensors have to observe and monitor their in-door environment, and then to report the data collected to a nearest information collector, referred to as the sink node. Sensor nodes which are far away from the sink relay their data via multiple hops to reach the sink. This way of communication makes the sensors near the sink deplete their energy much faster than distant nodes because they carry heavier traffic. So what is known as a hole appears around the sink and prevents distant nodes to send their data. Consequently the network lifetime ends prematurely. One efficient solution for this problem is to relocate sinks. In this work, we aim to find the best way to relocate sinks by determining their optimal locations and the duration of their sojourn time. So, we propose an Integer Linear Programming for multiple mobile sinks which directly maximizes the network lifetime instead of minimizing the energy consumption or maximizing the residual energy, which is what was done in previous solutions. Simulations results show that with our solution, the network lifetime is extended and the energy depletion is more balanced among the nodes. We also show that relocating mobile sinks inside a whole network is more efficient than relocating mobile sinks inside different clusters and we can achieve almost 52 % network lifetime improvement in our experiments.

Index Terms

Wireless Sensor Networks, Sinks positioning, Mobile sinks, Network lifetime, Integer Linear Programming.

1. Introduction

The need for Wireless Sensor Networks (WSNs) is rapidly growing in a wide range of applications specially for buildings automation. Such networks are composed of inexpensive and small nodes with sensing, data processing and communication capabilities. These sensors have a short operational life because they are equipped with limited batteries supplied energies which are usually impractical and even impossible to replace or recharge. These sensors are densely deployed in a region of interest and collaborate to forward the data collected towards a nearest information collector, referred to as the sink node. The sensor nodes which are far away from the sink use a multi-hop connections. This way of communication makes the sensors near the sink deplete their energy much faster than distant nodes because they carry heavier traffic. So what is known as a hole appears around the sink and prevents distant nodes to send their data. Consequently, the network lifetime ends prematurely. One efficient solution for this problem is to relocate sinks in order to guarantee balanced energy consumption among nodes. In this work, our purpose is to determine where to place multiple sinks inside buildings, how long they have to stay in certain locations and where to move them to extend the network lifetime. To answer these questions, we propose an Integer Linear Programming (ILP) for multiple mobile sinks whose objective function directly maximizes the network lifetime instead of minimizing the energy consumption or maximizing the residual energy, which is what was done in previous solutions. The contribution of our work concerns not only the definition of an ILP which determines the optimal locations of multiple mobile sinks but also show that relocating mobile sinks inside a whole network is more efficient than relocating mobile sinks inside different clusters. Simulation results show that with our proposed solution, the network lifetime is extended and the energy consumption is more balanced among the nodes. Moreover, the lifetime improvement that can be achieved when relocating sinks in the entire network is almost 52 % in our experiments. Such results can provide useful guidelines for real sensor network deployment.

The paper is organized as follow. In Section 2, we review the previously proposed solutions for the WSNs lifetime extension. Section 3 describes the system model. Section 4 presents the formulation of our proposed ILP for multiple mobile sinks. Section 5 shows the experimental results. Section 6 concludes the paper.

2. Related Work

In order to solve the problem of energy hole, many researchers look for approaches that help to extend the network lifetime. Some solutions propose to place more sensors nodes around the sink [1], [2]. However, these solutions are not always feasible in practice and result in unbalanced sensing coverage over different regions of the network. Another proposed solution is to deploy multiple static sinks in order to distribute load among the nodes [3], [4]. But, it has been proved in [5] that using a mobile sink is more efficient than a static one and thus helps to increase the network lifetime. Most of published works treat the problem of relocating a single sink [5], [6], [7], [8]. But, very few research focused on relocating multiple sinks. In [7], the solution of repositioning a single sink is extended to a network including several sinks by organizing it into several clusters. In [9], the authors propose a multi-sinks movement approach based on a local search algorithm. Some research efforts have focused on approaches that maximize the residual energy as in [10], [11], or minimize the average distances between sensors and closest sinks as in [12], to determine the optimal locations of mobile sinks. The first work that addressed the problem of positioning multiple mobile sinks is presented in [13]. The authors propose an ILP which determines the optimal locations of mobile sinks by minimizing the energy consumed at each node. In our work, a different formulation of the problem is proposed, where the ILP proposed directly maximizes the network lifetime instead of minimizing the energy consumption or maximizing the residual energy. To us, this is closer to the need of sensors deployment in building monitoring.

3. System Model

In order to deploy sensors and sinks inside buildings, we made the following assumptions for the system model.

3.1. Network Model

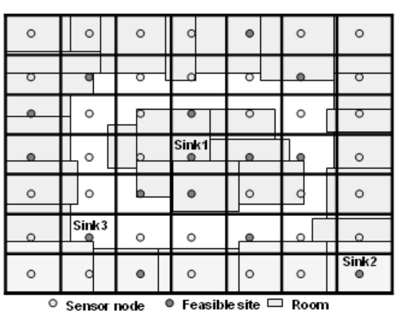


Figure 1. Grid of cells with sensors

All sensors are stationary and located in a grid of same size cells constructed from the building plan as shown in Figure 1. They all have a limited initial energy supply and a fixed transmission range equal to the distance between two nodes. Each sensor generates regularly the same amount of data. The sinks whose number is fixed and known a priori, can be located only in feasible sites where they get power and internet. They keep moving in the grid from feasible site to another one until the first sensor dies. The sinks should stay at a feasible site for at least a certain duration of time. At the end of this duration, they may stay or change of location. The traveling time of sinks between feasible sites is considered negligible for analytical simplicity.

3.2. Routing and Path Selection

The sensor nodes which aren't co-located with any sinks inside the grid, relay their generated data via multiple hops to reach the nearest sink. The sinks can be located only in feasible sites where they get power and network. They keep moving in the grid from feasible site to another one until the first sensor dies. When a sensor node is located in the same horizontal or vertical line of the nearest sink position, there is only one shortest path between the two nodes. Otherwise, there are multiple shortest paths. In our routing protocol like in [8], we route "per dimension". We consider only the two paths along the perimeter of the rectangle, i.e., paths 1 and 2 in Figure 2. These two routes are considered equivalent.

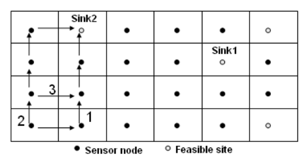


Figure 2. Path selection

3.3. Power Consumption

To calculate the power consumption, we consider the same realistic model as in [8]. Therefore, the power expended to transmit a L_1-bit/s packet to a distance d is:

$$P_{T_x} = L_1\gamma_1 + L_1\gamma_2 d^{\beta} \tag{1}$$

where γ_1 is the energy consumption factor indicating the power consumed per bit by the sensor to activate transceiver circuitry, γ_2 is the energy consumption factor indicating the power consumed per bit by the transmit amplifier to achieve an acceptable energy per bit over noise spectral density and β is the path loss exponent. The power expended to receive L_2-bit/s in the same radio model is:

$$P_{R_x} = L_2\alpha \tag{2}$$

where α is the energy consumption factor indicating the power consumed per bit at receiver circuit. Thus, the total energy consumed at a sensor node per time unit is:

$$P_{total} = P_{T_x} + P_{R_x} = L_1(\gamma_1 + \gamma_2 d^{\beta}) + L_2\alpha \tag{3}$$

4. Integer Linear Programming Formulation

The WSN is represented by the graph $G(V, E)$, where $V = S \cup F$ and $E \subseteq V \times V$. S represents the set of sensors nodes, F represents the set of feasible sites and E represents the set of wireless links. We distinguish two scenarios with mobile sinks. The first one is when there are multiple sinks moving in the entire network. The second one is when there are multiple sinks moving separately inside different clusters.

4.1. Mobile sinks moving in the entire network

The parameters and variables used to describe the problem are the following:

- Parameters
  - m is the number of sinks.
  - T (s) is the minimum duration of common time units for which the sink should stay at a certain feasible site.
  - e_0 (J) is the initial energy of each sensor.
  - e (J/bit) is the energy consumption coefficient for transmitting or receiving one bit.
  - r (bit/s) is the rate at which data packets are generated.
  - f_{ij}^k (bit/s) is the data transmission rate from node i to node j where the nearest sink stays at node k.
  - N_i^k is the set of i's neighbors whose their nearest sink is at node k.
  - $p_i^{k_1 k_2 .. k_m}$ (J/s) is the power consumed in sending and receiving data by sensor node i when the first sink is located at node k_1, the second sink is located at node k_2 etc. and the m-th sink is located at node k_m.
  - p_i^k (J/s) is the power consumed in sending and receiving data by senor node i when the nearest sink is located at node k, $k \in F$.

- Variables
  - Z (s) is the network lifetime.
  - $l_{k_1 k_2 .. k_m}$ is an integer variable which represents the number of times when the first sink is located at node k_1, the second sink is located at node k_2 etc. and the m-th sink is located at node k_m for a duration of time T. $k_1 \in F$, $k_2 \in F$ and $k_m \in F$.

$$\max\ Z = \sum_{k_1 \in F} \sum_{k_2 \in F} .. \sum_{k_m \in F} T\, l_{k_1 k_2 .. k_m} \quad (4)$$

$$\sum_{k_1 \in F} \sum_{k_2 \in F} .. \sum_{k_m \in F} T\, l_{k_1 k_2 .. k_m}\, p_i^{k_1 k_2 .. k_m} \leq e_0, \ \ i \in S \quad (5)$$

$$l_{k_1 k_2 .. k_m} \geq 0, \ k_1 \in F, k_2 \in F, .., k_m \in F \quad (6)$$

The equation (4) maximizes the network lifetime and determines the sojourn times of all sinks at feasible sites. The equation (5) assures that the energy consumed in receiving and transmitting data by each sensor node doesn't exceed its initial energy. This energy is computed when the first sink is located at node k_1, the second sink is located at node k_2 etc. and the m-th sink is located at node k_m.

The power $p_i^{k_1 k_2 .. k_m}$ is computed as following:

$$p_i^{k_1 k_2 .. k_m} = p_i^k \quad (7)$$

where k=$NearestSink(k_1, k_2, .., k_m, i)$, $NearestSink$ is a function which returns the nearest sink node to sensor node i. This sink node is determined by choosing the shortest path as presented in Section 3.2.

In the real world, the energy spent for receiving data exceeds the energy spent for transmitting data. In our model as in [8], we assume that the energy consumed when transmitting a bit is constant and equal to energy consumed when receiving a bit, here denoted by e (J/bit) i.e., $\gamma_1 + \gamma_2 d^\beta \approx \alpha$ $=e$. Thus, we obtain:

$$P_{total} = e(L_1 + L_2) \quad (8)$$

So, in our model the p_i^k is calculated as following [8]:

$$p_i^k = e\Big(\sum_{j \in N_i^k} f_{ij}^k + \sum_{j : i \in N_j^k} f_{ji}^k\Big), \ i \in S, \ \ k \in F \ and\ i \neq k \quad (9)$$

$$p_i^k = er, \ i \in S, \ \ k \in F \ and\ i = k \quad (10)$$

At each node, the total of outgoing packets is equal to the total incoming packets plus the data packets generated:

$$\sum_{j : i \in N_j^k} f_{ji}^k + r = \sum_{j \in N_i^k} f_{ij}^k, \ i \in S, \ \ k \in F \quad (11)$$

Using the two equations (9) and (11), we obtain:

$$p_i^k = e\Big(2 \sum_{j : i \in N_j^k} f_{ji}^k + r\Big), \ i \in S, \ \ k \in F \ and\ i \neq k \quad (12)$$

4.2. Mobile sinks moving separately in clusters

In this section, we formulate an ILP for a network divided in different clusters. The movement of the sinks is restricted to their cluster.

The variables and parameters that differ from section 4.1:

- Z_j (s) is the network lifetime of the cluster j, $j \in \{1, 2, .., m\}$
- l_k is an integer variable which represents the number of times when the sink is located at node k, $k \in F_j$ for a duration of time T.

- p_i^k (J/s) is the power consumed in sending and receiving data by senor node i when the sink is located at node k, $k \in F_j$.
- F_j is the set of feasible sites of cluster j, $j \in \{1, 2, .., m\}$ and $F = \cup F_j$.
- S_j is the set of sensor nodes of cluster j, $j \in \{1, 2, .., m\}$ and $S = \cup S_j$.

For each cluster j, $j \in \{1, 2, ..m\}$

$$\max\ Z_j\ = \sum_{k \in F_j} T\ l_k \tag{13}$$

$$\sum_{k \in F_j} T\ l_k\ p_i^k \leq e_0,\ \ i \in S_j \tag{14}$$

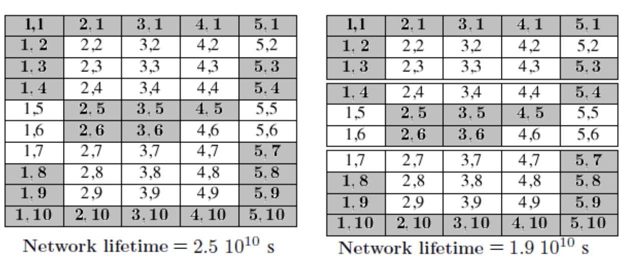
$$l_k \geq 0,\ k \in F_j \tag{15}$$

The lifetime of network which is the time until the first sensor dies is determined by the following equation.

$$Z = \min_j(Z_j) \tag{16}$$

5. Simulation and Results

We simulated a sensor network of 50 nodes distributed in a 5x10 grid. We considered 3 sinks moving in 25 chosen feasible sites. We also simulated the same network with the same number of nodes and feasible sites but divided in 3 predefined clusters (5x3), (5x3) and (5x4) in which 3 sinks move separately as shown in the Figure 3. Each node in the grid is localized with its coordinates (x,y) where x is the column position and y is the row position. The results show that the network lifetime improvement is 31 % when the sinks move in the entire network.



(a) The entire network (b) Network divided in clusters

Figure 3. Each grid cell has a sensor. The feasible sites are colored. The 3 clusters (5x3), (5x3) and (5x4) are separated by space

In order to determine the network lifetime and the optimal location of sinks, we solved the proposed ILP with GLPK solver version 4.34 [14]. The calculation of the power consumed by senor node when the nearest sink is located at certain node (p_i^k) was made by a program written in Java. The values of parameter variables were chosen according to the following realistic assumptions. The initial energy at each node was chosen equal to energy found in two Alkaline batteries AA of 1.5V and 2600mAh i.e., e_o= 28080 J. We also chose the energy consumption coefficient for transmitting and receiving one bit the same as vendor-specified values for the Chipcon CC2420 [15] where $E_{Tx} = 0.225\ 10^{-6}$ J/bit and $E_{Rx} = 0.2625\ 10^{-6}$ J/bit. We assume that $e = E_{Tx} = E_{Rx}$= 0.2625 10^{-6} J/bit. We fixed the minimum duration of sojourn time T of the sinks to 30 days (T = 2592000 s) because it is economically not easy for technicians to relocate sinks in buildings very often. The rate r at which data packets are generated is equal to 1 bit/s. Notice that real micro-controllers stop running when the battery voltage is below a threshold. This depends on the micro-controllers and can not be taken into account here.

To get deeper understanding of the efficiency of the sinks mobility in the entire network, we simulated sensor networks with different grid sizes and number of sinks. We investigated the network lifetime, the pattern of the distribution of the sinks sojourn times at the different nodes and the residual energy at each node. We assumed the same number of feasible sites as sensor nodes. We considered the three following cases in order to make a comparative study.

1) Stationary sinks.
2) Mobile sinks moving in different clusters
3) Mobile sinks moving in the entire network

To compute the network lifetime and the optimal locations of stationary sinks, we used the following equation [8]:

$$Z = \max_k\{\min_i(\frac{e_0}{p_i^k})\},\ k \in F,\ i \in S \tag{17}$$

where $k = NearestSink(k_1, k_2, .., k_m, i),\ \ k_1 \in F, k_2 \in F, .., k_m \in F$.

5.1. Network lifetime

To study the network lifetime, we run our ILP with an increasing number of sensor nodes and sinks. Then, we compared the network lifetime for each of the cases above.

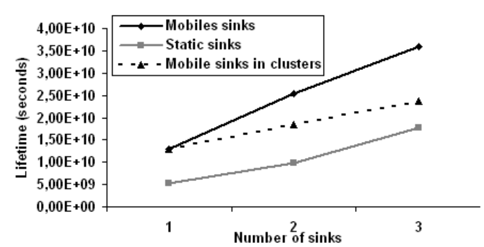
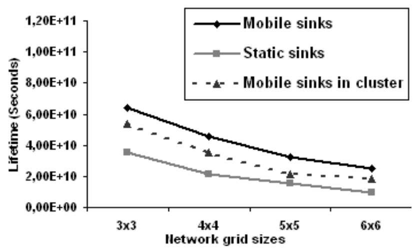
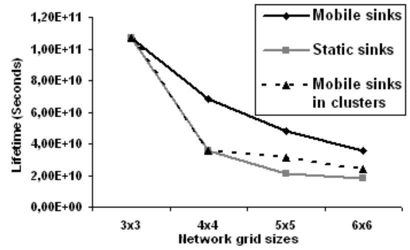


Figure 4. The network lifetime in 6x6 grid

Figure 4 shows that the network lifetime increases when the number of sinks increases for all the cases. However,



(a) 2 sinks



(b) 3 sinks

Figure 5. The network lifetime in different network grids

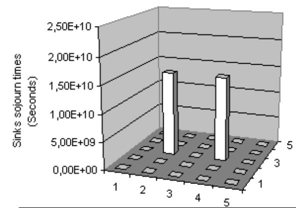
the first sensor dies relatively quickly when the sinks are statics or moving in different clusters comparing to when the sinks are moving in the whole network. In the case of static sinks, the network lifetime is clearly shorter than mobile sinks because nodes around sinks have to spend more energy to relay packets for important number of nodes which leads them to drain their energy faster. The lifetime improvement ratios obtained in 6x6 grid by deploying 3 mobile sinks in the entire network are 52 % against 3 mobile sinks moving separately in different clusters and 102 % against 3 static sinks.

Figure 5 shows that when the network size is bigger the network lifetime is shorter for all of the cases. This is explained by the fact that there is more data traffic. Hence, sensors which are near the sinks must retransmit a higher number of packets from their higher number of neighbors which leads to faster energy depletion.

5.2. The Sinks Sojourn Times

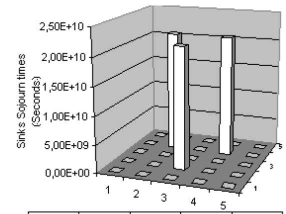
We investigated the pattern of the distribution of the sinks sojourn times at the different nodes with different number of sinks. Without loss of generality, we considered 5x5 grid. Independently of the size of the network, we observe that for all the cases, the sinks sojourn most of times at the nodes which are at minimum distance i.e., number of hops to all other nodes.

The optimal sinks locations obtained for static sinks are the nodes with the coordinates (2,3) and (4,3) when there are 2 sinks in the network and the nodes with coordinates (3,2), (2,4) and (4,4) when there are 3 sinks in the network (see Figure 6).



	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	1,53E+10	0	1,53E+10	0
4	0	0	0	0	0
5	0	0	0	0	0

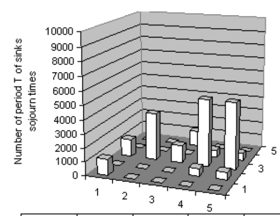
(a) 2 static sinks



	1	2	3	4	5
1	0	0	0	0	0
2	0	0	2,14E+10	0	0
3	0	0	0	0	0
4	0	2,14E+10	0	2,14E+10	0
5	0	0	0	0	0

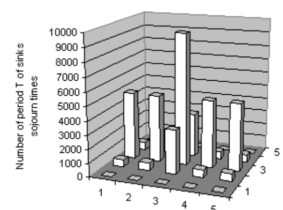
(b) 3 static sinks

Figure 6. Static sinks sojourn times at the different nodes



	1	2	3	4	5
1	1154	0	1	0	0
2	0	0	0	542	543
3	1300	3463	1297	4888	4888
4	0	0	0	542	543
5	0	0	1153	0	0

(a) 2 mobile sinks in 2 clusters 3x5 and 2x5

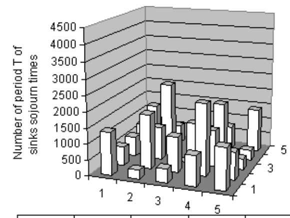


	1	2	3	4	5
1	0	0	0	0	0
2	542	543	3174	542	543
3	4888	4888	9524	4888	4888
4	542	543	3174	542	543
5	0	0	0	0	0

(b) 3 mobile sinks in 3 clusters 2x5, 1x5 and 2x5

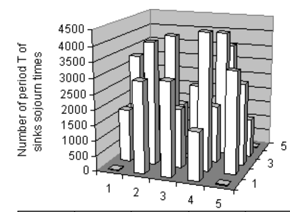
Figure 7. Mobile sinks sojourn times at different clusters nodes. The clusters are separated double lines

The grid 5x5 was divided in different predefined clusters in which the sinks move separately. The sojourn times of sinks at the different nodes of clusters are shown in Figure 7. We notice that each sink sojourns most of times at the central grid area and/or the corners of its cluster.



	1	2	3	4	5
1	1361	279	431	966	1325
2	593	1740	1129	2271	875
3	643	1059	9	1159	351
4	786	2237	1006	1748	331
5	1194	594	562	730	1414

(a) 2 mobile sinks



	1	2	3	4	5
1	5	2974	3050	1582	12
2	1717	4009	1935	4440	3319
3	3336	2108	10	1865	2688
4	3088	3893	2239	4106	1253
5	15	1279	3284	3521	8

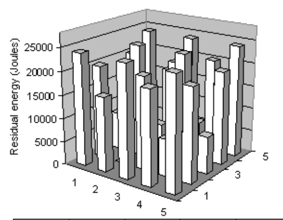
(b) 3 mobile sinks

Figure 8. Mobile sinks sojourn times at the different nodes in the entire network

For the case of sinks moving in the entire network, the sinks sojourn most of the times at the central grid area as shown in Figure 8. For the case of 2 sinks in the network, the two locations in which the sinks stay the most of times are the nodes with coordinates (4,2) and (2,4). For the case of 3 sinks in the network, the three locations in which the sinks stay the most of times are the nodes with coordinates (2,2), (4,2) and (4,4).

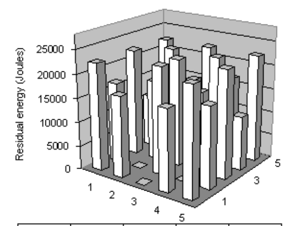
5.3. Residual energy

We investigated the residual energy at each sensor node at the end of network lifetime for different number of sinks. Without loss of generality, we considered a 5x5 grid. We compared between the three different cases above.



	1	2	3	4	5
1	24068,571	16045,714	24068,571	20057,143	24068,571
2	20057,143	0	20057,143	8022,8571	20057,143
3	8022,8571	24068,571	8022,8571	24068,571	8022,8571
4	20057,143	0	20057,143	8022,8571	20057,143
5	24068,571	16045,714	24068,571	20057,143	24068,571

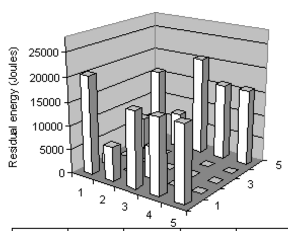
(a) 2 static sinks



	1	2	3	4	5
1	22464,00	16848,00	0,00	16848,00	22464,00
2	16848,00	0,00	22464,00	0,00	16848,00
3	22464,00	16848,00	22464,00	16848,00	22464,00
4	11232,00	22464,00	16848,00	22464,00	11232,00
5	22464,00	11232,00	22464,00	16848,00	22464,00

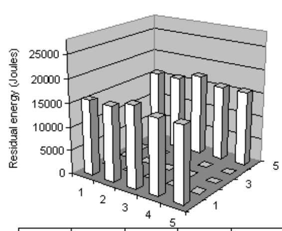
(b) 3 static sinks

Figure 9. Residual Energy at the end of the network lifetime of 5x5 grid with static sinks



	1	2	3	4	5
1	20614,651	7263,8424	15911,726	15888,593	15887,232
2	2061,504	2,6136	6778,7172	0,5724	1,2528
3	9,4176	5,3352	1,2528	8,0568	1,2528
4	6775,3152	5,3352	2078,514	0,5724	1,2528
5	15909,005	7276,0896	20620,094	15888,593	15887,232

(a) 2 sinks in clusters 3x5 2x5

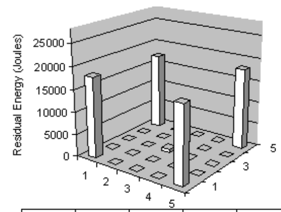


	1	2	3	4	5
1	15888,59	15887,23	17280,69	15888,59	15887,23
2	0,5724	1,2528	1,2528	0,5724	1,2528
3	8,0568	1,2528	3,9744	8,0568	1,2528
4	0,5724	1,2528	1,2528	0,5724	1,2528
5	15888,59	15887,23	17280,69	15888,59	15887,23

(b) 3 sinks in clusters 2x5 1x5 2x5

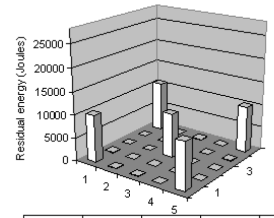
Figure 10. Residual Energy at the end of the network lifetime of 5x5 grid with mobile sinks in clusters

It is remarkable in the Figures 9, 10 and 11 that the energy consumption is highly variable and depends on the sinks locations for all the cases. The nodes which aren't along any routing path to reach the sink have relatively higher energies compared to most of the others, because they don't have as nodes closest to the sinks to receive and relay all other neighbors data in addition to their own data. This, leads them to consume less energy. The same remark is made



	1	2	3	4	5
1	18027,77	5,3352	36,6336	17,5824	17205,17
2	3,294	17,5824	2,6136	2,6136	1,2528
3	0,5724	6,696	849,0312	17,5824	1,2528
4	11,4588	9,4176	27,108	9,4176	1,9332
5	17120,8	8,0568	27,7884	7,3764	18054,99

(a) 2 mobile sinks



	1	2	3	4	5
1	10294,344	47,52	8,7372	14,1804	10274,612
2	69,2928	3,9744	12,8196	35,2728	59,7672
3	88,344	17,5824	9581,9652	0,5724	152,3016
4	69,9732	57,0456	3,9744	33,2316	65,8908
5	10914,188	30,51	89,0244	3,9744	10224,263

(b) 3 mobile sinks

Figure 11. Residual Energy at the end of the network lifetime of the 5x5 grid with mobile sinks

for nodes visited by the sinks and at the same time did not need to relay any data. For example in the Figure 11(b), sensor nodes with coordinates (1,1), (5,1), (3,3), (1,5), (5,5) have higher energy remained unused at the end of network lifetime than the others nodes. This can be explicated by the fact that they don't have to drain their energy in forwarding neighbor's data since the sinks are most of times located in the nodes with coordinates (2,2), (4,2) and (4,4).

In general, we observe that at the end of network lifetime the distribution of residual energy in the grid is more balanced and the energy is more consumed among the nodes when the number of sinks increases. With static sinks, the majority of sensors have more residual energy at the end of network lifetime than in the cases with mobile sinks which have their initial energies almost completely depleted at the same time. In fact, in 5x5 grid as shown in the Figures 9, 10 and 11, the rate of the energy remained unused at the network lifetime end is 50 % for 3 static sinks, 23 % for 3 mobile sinks in different clusters and 7 % for 3 mobile sinks in the entire network. Moreover, the numbers of sensors which have more than 50 % of their initial energy remained unused is 19 for the case of 3 static sinks, 10 with 3 mobile sinks moving separately in clusters and 0 for the case of mobile sinks moving in the whole network. For the case of sinks moving in the whole network, sensor nodes have their energy more consumed among the nodes than in the case of sinks moving in clusters. This is due to the fact that the mobility of sinks in the whole network changes the nodes acting as relays frequently and leads to balanced energy consumption among nodes. While, in the third case, the movement of the sinks is restricted to their own clusters. So, this approach prevents to have global view of the entire network.

These results are interesting since they aren't pure theory because we tried to approach realistic buildings deployment in our assumptions and especially with sinks that can't move frequently.

6. Conclusion

In this paper, we have explored the problem of positioning mobile sinks in wireless sensor networks inside buildings, to avoid the energy hole problem and to extend the network lifetime, which is really needed in practice. As a solution, we have proposed an ILP which directly maximizes the network lifetime instead of minimizing the energy consumption or maximizing the residual energy, which is what was done in previous solutions. The proposed ILP determines the best way to relocate sinks by giving their optimal locations and the duration of their sojourn time. A comparative study of the proposed solution with static sinks and mobile sinks moving separately in clusters was made. Relocating sinks with our solution and using realistic parameters assumptions results in the network lifetime extension and the energy consumption more balanced among the nodes. The lifetime improvements achieved in our experiments by deploying 3 mobile sinks in the entire network are almost 52 % against 3 mobile sinks moving separately in different clusters and almost 102 % against 3 static sinks. The study of the pattern of the distribution of the sinks at different locations showed that the sinks sojourn most of times at the nodes which are at minimum number of hops to all other nodes specially in the central grid area. This corresponds to very interesting feasible sites in buildings corridors.

In our future work, a real deployment of multiple sinks according to our proposed solution in a sensor network inside buildings is envisaged. We intend to study not only the lifetime, the pattern of the distribution of the sinks at different locations and the residual energy but also the performance of the network for this configuration such as latency, bandwidth and data delivery ratio.

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