Exploiting Sink Mobility for Maximizing Sensor Networks Lifetime

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***Abstract*— This paper explores the idea of exploiting the mobility of data collection points (sinks) for the purpose of increasing the lifetime of a wireless sensor network with energy-constrained nodes. We give a novel linear programming formulation for the joint problems of determining the movement of the sink and the sojourn time at different points in the network that induce the maximum network lifetime. Differently from previous solutions, our objective function maximizes the overall network lifetime (here defined as the time till the first node “dies” because of energy depletion) rather than minimizing the energy consumption at the nodes. For wireless sensor networks with up to 256 nodes our model produces sink movement patterns and sojourn times leading to a network lifetime up to almost five times that obtained with a static sink. Simulation results are performed to determine the distribution of the residual energy at the nodes over time. These results confirm that energy consumption varies with the current sink location, being the nodes more drained those in the proximity of the sink. Furthermore, the proposed solution for computing the sink movement results in a fair balancing of the energy depletion among the network nodes.**

I. INTRODUCTION

Wireless sensor networks (WSN) are networks usually comprised of a large number of nodes with sensing and routing capabilities [1]. Multi-hop routing is usually implemented for the transport of the sensed data to special data collection nodes (the sinks). Among the challenges posed by the problem of data delivery to the sinks one that has recently received considerable attention concerns the minimization of the node energy consumption for increasing the overall network lifetime. Previous research aimed toward this major goal has been prevalently concerned with developing techniques for topology control [2], [3], energy efficient MAC [4] and routing [5], [6].

Most of the considered scenarios deal with sensor nodes that do no move and are un-replaceable, where the sensed data have to be delivered to the sinks that are static as well.

A trend of the research on data dissemination in WSNs has recently started where the mobility of some of the nodes is exploited to facilitate the delivery of the sensed data to the sinks.

Considering mobility as “a blessing” rather than a curse to network performance has been widely discussed for general ad hoc networks in different contexts [7]–[10]. The primary objective of these works is to deliver messages in disconnected ad hoc networks and to improve network throughput.

The work by Chatzigiannakis et al. [8] explores the possibility of using the coordinated motion of a small part of users in the network to achieve efficient communication between two other mobile nodes. Basically, a part of the network nodes act as forwarding agents carrying packets for other nodes: The packet is exchanged when the source node and the agent are neighbors (i.e., in the radio vicinity of each other), and it is then delivered to the intended destination when the agent passes by it.

This basic idea has been introduced to WSNs by Shah et al. in their works on *data mules* [11]. Mobile nodes in the sensor field, called mules, are used as forwarding agents. The idea here is to save energy by having single-hop communication (from a sensor to the mule that is passing by) instead of the more expensive multi-hop routing (from the sensor to the sink): It is the mule that will eventually take the sensed data to the sink. This approach has been further investigated by Kim et al. [12] which propose a dissemination protocols in which a tree-like communication structure is built and maintained and mobile sinks access the tree from specified sensor nodes in the tree. The protocol, termed SEAD (Scalable Energy-Efficient Asynchronous Dissemination), demonstrates the effectiveness of deploying mobile sinks for energy saving with respect to the static case via simulation. SEAD is shown to be more effective for energy conservation than directed diffusion [13], TTDD [14] and ADMR [15].

In all these works, the mobility of the sink is unpredictable. For instance, sinks move according to the random waypoint model [12].

A first attempt on how to determine specific sink movements for energy minimization is presented in [16]. The authors present an ILP (Integer Linear Programming) model to determine the locations of multiple sinks in the case multi-hop routing to the sink is allowed (a flow-based routing protocol is used). The model aims at minimizing the energy consumption per node and the total energy consumption during a given time. The authors argue that minimizing the energy consumption yields to improved network longevity (although figures of this improvement are not given). In order to obtain stronger energy saving results, the authors consider also the presence of multiple sinks in the network. The ILP model is used to determine feasible locations the sinks should travel to for minimizing energy consumption.

In this paper we are concerned with the joint problems of determining the movements of the sink and the times the sink sojourns at certain network nodes so that network lifetime is maximized. We consider WSNs where the $n = L^2$ homogeneous nodes are arranged in a bi-dimensional grid and one mobile sink travels through them. For this model, we present a novel linear programming formulation for the network lifetime maximization problem which is elegantly simple, yet capable of expressing network lifetime in terms of sink sojourn time at the nodes. Differently from the ILP formulation in [16], our objective function concerns the overall network lifetime (here defined as the time till the first node "dies" for energy depletion) directly, instead of indirectly deducing it from the greedy minimization of the energy consumptions at the nodes. The model is solved for WSNs with up to 256 nodes. Improvements are obtained which are almost five-fold when the sink sojourns at the four corner areas and at the central area of the grid.

Simulation results demonstrate that by moving the sink according to the pattern determined by solving the linear programming formulation, we obtain an even distribution of the nodes' residual energy, which leads to a significant increase in network lifetime.

The paper is organized as follows. In the next section we describe the assumptions made for describing a WSN. In Section III, a linear programming formulation is given for the problem of maximizing the network lifetime by having the sink sojourning at certain locations (grid nodes) for certain times. Analytical results are given in Section IV that show the improvement in network lifetime obtained by moving the sink. Simulation results are finally proposed in Section V, where we show the distribution of the residual energy at the nodes over time. Section VI concludes the paper.

II. SYSTEM MODEL

We make the following simplifying assumptions in building the system model:

- Sensors remain stationary at the nodes of a bi-dimensional square grid composed of same-size cells.
- The sink can move freely on the grid from one node to another. During its sojourn time at a node, sensors can communicate with the sink. For analytical simplicity, the traveling time of the sink between two nodes is considered negligible.
- Data transmission and reception are the major energy consuming activities.
- Sensor nodes are homogeneous and wireless channels are bi-directional, symmetric and error-free.
- Each node has a limited initial energy and unlimited buffer size.
- Sensor nodes communicate with the sink by sending data via multiple hops along the shortest path; a hop is of one cell side length, i.e., the distance between two adjacent nodes in the grid equals the nodes' transmission range.

The sensor network is modeled as a graph $G(N, E)$ where N is the set of all the nodes in the square grid and E is the set of all links (i, j) where i and j are neighboring nodes. A node i can communicate directly with its (at most) four neighboring nodes. Let S_i be the set of i's neighbors.

Each sensor generates data packets at a fixed data rate. If a sensor node i is neither co-located with sink k nor directly connected with it (i.e., if k is not co-located with any of the nodes in S_i), then data packets generated at node i have to be relayed through multiple hops to reach the sink. The sink can only be located at one node position in the grid (the sensor locations and the possible sink locations are the same). The sink keeps moving among grid positions until the maximum network lifetime is reached, which occurs when one sensor node's residual energy drops below a predefined threshold required for it to operate (when this happens the sensor "dies"). In our model *the network lifetime is calculated as the sum of sojourn times of the sink at all visited nodes*. The sojourn times are constrained by the fact that the total energy spent by each node when the sink is co-located with different nodes cannot exceed the sensor node initial energy.

When a sensor node lies on the same horizontal or vertical line of the current position of the sink, a unique shortest path exists between the two nodes. Otherwise, multiple shortest paths exist. For example, six shortest paths exist between sensor i and sink k (Figure 1), each four hops long. Three of those paths are shown, path 1 and 2 along the perimeter of the rectangle defined by nodes i and k, and path 3, one of the four interior paths. In our routing protocol we consider only the two paths along the perimeter of the rectangle, i.e., paths 1 and 2 in Figure 1. These two routes are taken at equal frequencies, or equivalently, the route alternates between the two paths.

When calculating power consumption, the *first order radio* model is frequently used. For receiving k_1 bits/sec, the power consumption (p_r) at a sensor node is

$$p_r = k_1\beta$$

where β is a factor indicating the energy consumption per bit at the receiver circuit. The power p_t needed for transmitting k_2 bits/sec is

$$p_t = k_2(\alpha_1 + \alpha_2 d^p)$$

where α_1 is the energy consumption factor indicating the power consumed per bit by the transmitter circuit and $\alpha_2 d^p$ indicates the energy consumption on the amplifier (per bit), d being the physical distance between the transmitting and the

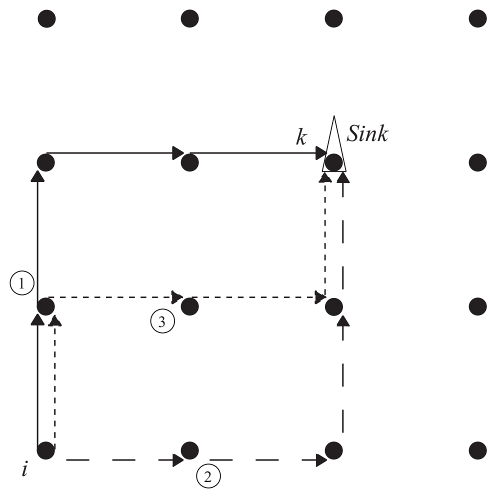

Fig. 1. Shortest paths from a sensor to the sink

receiving node and p the path loss exponent (usually between 2 and 4, depending on the environment).

The transmission radius of a sensor node is usually very limited (of the order of a few tens of meters) so that the energy spent for the transceiver circuitry exceeds the energy consumption due to the emitted power. According to the energy model of real-life sensor nodes prototypes we adopted an energy model in which the energy consumed when transmitting is basically constant, and in which the energy consumed for receiving a bit is the same as the energy consumed for transmitting a bit, here denoted by e:

$$\beta \approx \alpha_1 + \alpha_2 d^p = e$$

Therefore the total energy consumption at a node per time unit is:

$$p_r + p_t = k_1\beta + k_2(\alpha_1 + \alpha_2 d^p) \approx e(k_1 + k_2). \qquad (1)$$

III. MATHEMATICAL FORMULATION

We start by describing the parameters and the variables used for describing our problem formally.

Parameters

- e_0: Initial energy (Joules) of each node minus the threshold energy required for node operation.
- e: Energy consumption coefficient for transmitting or receiving one bit (Joules/bit).
- n: Number of sensor nodes in the $L \times L$ grid.
- r: Rate at which data packets are generated (bits/sec), here considered the same for all nodes.
- f_{ij}^k: Data transmission rate from node i to node j while sink stays at node k (bits/sec).
- c_i^k: Power consumption for receiving and transmitting packets at node i when the sink sojourns at node k (Joules/sec).

Variables

- t_k: Sojourn time (secs) of the sink at node k ($k \in N$)
- z: Network lifetime (secs).

The power consumption at a sensor node i when the sink sojourns at node k is computed from (1) as follows.

$$c_i^k = e(\sum_{j \in S_i} f_{ij}^k + \sum_{j: i \in S_j} f_{ji}^k), \qquad i, k \in N \text{ and } i \neq k \qquad (2)$$

and

$$c_i^k = er, \qquad i, k \in N \text{ and } i = k. \qquad (3)$$

Equation 3 holds when the sink is co-located with node i and expresses the fact that all nodes in S_i communicate directly with the sink.[1]

Considering the data balance flow at each node, within each time unit, the total incoming data packets plus the data packets generated at the node equals the total outgoing data packets from the node:

$$\sum_{j: i \in S_j} f_{ji}^k + r = \sum_{j \in S_i} f_{ij}^k, \qquad i, k \in N \qquad (4)$$

Linear programming formulation

The Linear Programming (LP) model below determines the sojourn times t_k of the sink at each node $k \in N$ so that the network lifetime is maximized. If the optimal value for a t_k is 0 the sink does not visit node k. Every node $k \in N$ whose optimal t_k is positive is visited by the sink for a time duration equal to t_k. The sink visiting order is not important since the traveling time of the sink between nodes is considered negligible and data generation rate is independent of time.

$$\begin{aligned} \mathit{Max}\ z &= \sum_{k \in N} t_k && (5) \\ \text{such that} \quad & \sum_{k \in N} c_i^k t_k \leq e_0, \quad i \in N && (6) \\ & t_k \geq 0, \quad k \in N. && (7) \end{aligned}$$

The objective function (5) maximizes network lifetime, i.e., the sum of sojourn times of the sink at all visited nodes. The term $c_i^k t_k$ in (6) represents the energy consumed at node i for receiving and transmitting data during the time interval the sink sojourns at node k. The total energy consumed at each node is computed as the sum of the energies consumed over all sojourn times of the sink at visited nodes. Constraint (6) simply states that the energy consumed at each node i should not exceed the initial energy of that node. Constraint (7) assures the non-negativity of sojourn time t_k.

The calculation of c_i^k is illustrated below using the 5×5 grid of Figure 2.

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[1] In our model we assume that whenever a node i receives a packet that is not addressed to it the energy consumed for receiving it is negligible. This reflects the fact that after reading the first part of the packer header, or reading the RTS packet, the node can go to sleep for the remaining duration of the packet transmission time.

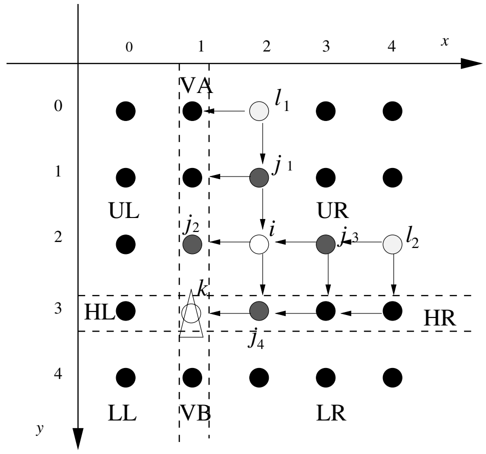

Fig. 2. Data flows received and transmitted at node i

We define each node's position using the ordered pair of the node's column and row number (x, y), $x = 0, 1, \ldots, L-1$, $y = 0, 1, \ldots, L-1$. A pair of horizontal and vertical dotted lines is drawn enclosing the nodes associated with the row and the column of the sink. These lines partition N into nine subsets as shown in Figure 2: UL (Upper Left), UR (Upper Right), LL (Lower Left), LR (Lower Right), VA (Vertical Above), VB (Vertical Below), HL (Horizontal Left), HR (Horizontal Right) and node k (with which the sink is co-located).

Equations (2) through (4) are used to accumulate flows and compute c_i^k. According to the routing protocol defined earlier, node i transmits its own generated packets to nodes j_2 and j_4, one half each. Nodes j_2 and j_4 relay these packets to the sink node k. In addition, node i receives half of the packets generated at nodes j_1 and j_3 and half of the packets generated at nodes l_1 and l_2. Then, node i retransmits the packets originated at nodes j_3 and l_2 to node j_2 and those originated at nodes j_1 and l_1 to node j_4. Note that $S_i = \{j_1, j_2, j_3, j_4\}$ and since $i \in UR$, node i receives only from nodes j_1 and j_3 and transmits to nodes j_2 and j_4. In summary, node i receives at a rate $2r$ and transmits at a rate $3r$, having therefore power consumption $c_i^k = 5re$. Depending on the position (x, y) of node i and the node subset to which it belongs, the following formulas can be derived for c_i^k:

$$c_i^k = \begin{cases} er[(x+1)(1+L)-1] & i \in HL \\ er[(L-x)(1+L)-1] & i \in HR \\ er[(y+1)(1+L)-1] & i \in VA \\ er[(L-y)(1+L)-1] & i \in VB \\ er(1+x+y) & i \in UL \\ er(L-x+y) & i \in UR \\ er(L+x-y) & i \in LL \\ er(2L-x-y-1) & i \in LR \\ er & i = k \end{cases}$$

The computation of c_i^k is programmed in C. Solution to the LP model for a given set of parameters has been obtained by using LINGO [17].

TABLE I

z_m, z_s AND IMPROVEMENT RATIO

L	(n)	z_m	z_s	$\frac{z_m - z_s}{z_s}\%$
3	(9)	802207.13	725806.45	10.53
4	(16)	451917.22	241935.48	86.79
5	(25)	320054.41	197947.21	61.69
6	(36)	263601.35	108870.97	142.12
7	(49)	222868.79	94670.41	135.42
8	(6)	193126.30	62211.98	210.43
9	(81)	169492.98	55831.27	203.58
10	(100)	151528.97	40322.58	275.79
11	(121)	137219.32	36905.41	271.81
12	(144)	125451.12	28278.17	343.63
13	(169)	115285.47	26233.97	339.45
14	(196)	106707.02	20936.73	409.66
15	(225)	99422.85	19616.39	406.84
16	(256)	93074.87	16129.03	477.06

IV. ANALYTICAL RESULTS

When the sink remains static, the maximum network lifetime and the node location at which it is achieved can be obtained by solving the following problem:

$$z_s = \max_k \{\min_i \frac{e_0}{c_i^k}\}, \qquad i, k \in N \tag{8}$$

Solving the LP model given in Section III and the model described by equation (8) on networks of 3×3, 4×4, $5 \times 5, \ldots$, 16×16 nodes, we obtain the results shown in Table I, where z_m denotes the optimal network lifetime in case of a mobile sink, and $\frac{z_m - z_s}{z_s}$ denotes the percentage improvement in terms of network lifetime when the sink is mobile instead of static. The values of the parameters are $r = 1$bit/sec, $e = 0.62\mu$J/bit, $e_0 = 1.35$J.

These results are depicted in figures 3 and 4.

Figure 3 shows that as the network size increases the network lifetime decreases. This is due to the fact that each node, acting as a relay for a higher number of nodes, has to receive and transmit a higher number of packets, which leads to faster energy depletion. In the case of static sink the network lifetime is clearly shorter since the sensor nodes close to the sink always relay the packets of all other nodes, which drains them of their energy quite fast.

Figure 4 displays the lifetime improvement ratio as it changes with L for a $L \times L$ grid where L is even or odd. We see that in both cases the improvement increases with the network size. For the grid with even number of nodes the improvement is higher due to a relatively lower z_s. When L is even the network lifetime is maximized when the sink stays at one of the four central nodes. For odd values of L the sink is instead co-located with the unique central node. This results in an uneven distribution of data flows, and thus in a lower network lifetime z_s in case of even values of L.

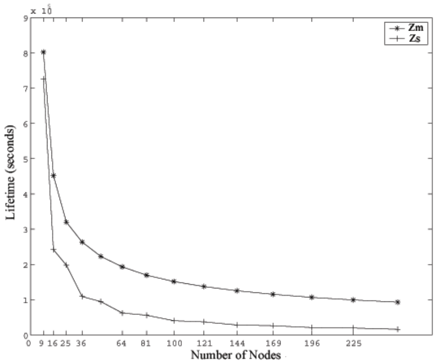

Fig. 3. z_m vs. z_s

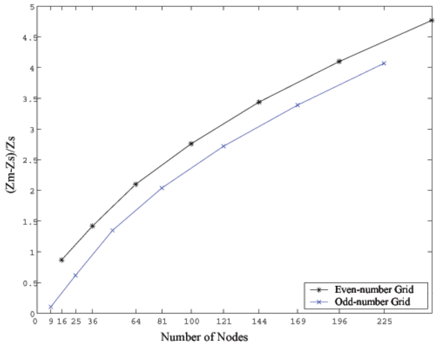

Fig. 4. Improvement ratio $(z_m - z_s)/z_s$

We have also investigated the pattern of the distribution of the sink sojourn times at the different nodes and the corresponding node energy consumption. Independently of the size of the grid, our results show a similar pattern: the sink sojourns mostly at the four corners (for most of the time), and in the grid central area. This implies that when the sink is at one of the four corners, the nodes close to it and along the row/column of the sink spend the most energy. By locating the sink at one of the corners all the nodes in that corner (except the one co-located with the sink) deplete their energy significantly.

In the case the sink starts by sojourning first at the four corners (order is irrelevant), the nodes in the central area still have a relatively high residual energy. This makes it appealing for the sink to move toward the central area to extend the network lifetime.

In general, as expected, we observed that the higher the network size, the more energy the nodes spend to deliver the data to the sink, the lower the sojourn times at the corners (their energy deplete faster), and the lower the residual energy at the central nodes when the four corners' low residual energy demands a sink relocation.

V. SIMULATION RESULTS

To obtain a deeper understanding of the results shown above, we studied the distribution of the nodes residual energy over time. As expected, our results confirmed that the nodes energy consumption is highly variable and depends on the current location of the sink. The nodes close to the sink and along the sink row/column are the ones experiencing the highest energy consumption. Without loss of generality, we consider an 8×8 grid and we investigate how energy is consumed at the nodes while the sink moves.

The optimal sink sojourn times at the nodes of this grid are given in Table II.

The sink is co-located with nodes in the four corner areas and with those in the central area of the grid. Therefore, we divide the network life into five "episodes," $E1$ through

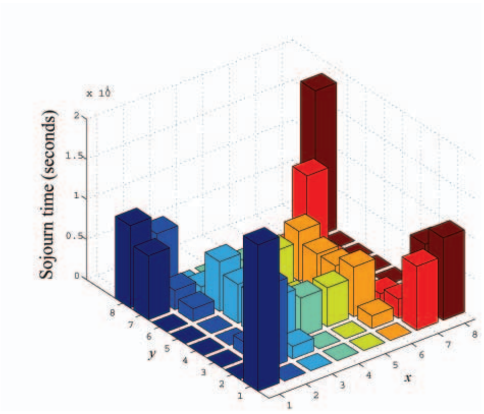

Fig. 5. Sink sojourn times for 8×8 networks

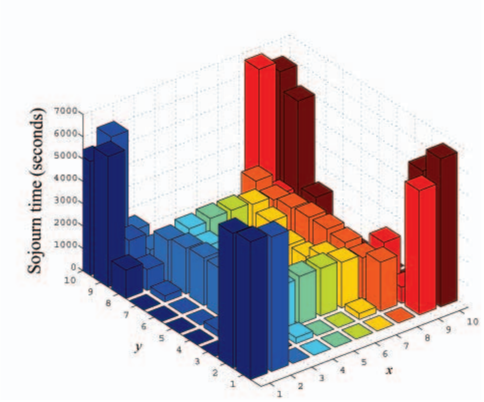

Fig. 6. Sink sojourn times for 10×10 networks

TABLE II

SINK SOJOURN TIMES FOR 8×8 NETWORKS (SECONDS)

18217	0	0	0	0	0	7966	10252
0	10362	1572	0	0	1572	2396	7966
0	1572	6184	4851	4851	6184	1572	0
0	0	4851	673	673	4851	0	0
0	0	4851	673	673	4851	0	0
0	1572	6184	4851	4851	6184	1572	0
7966	2396	1572	0	0	1572	10362	0
10252	7966	0	0	0	0	0	18217

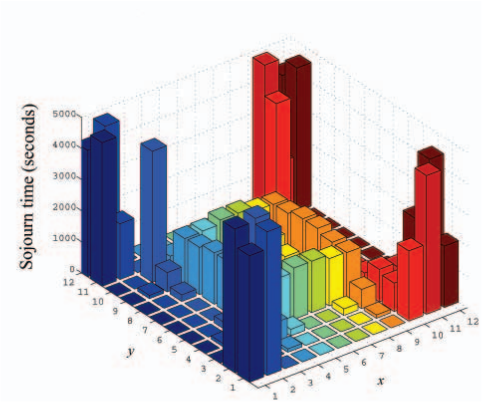

Fig. 7. Sink sojourn times for 12 × 12 networks

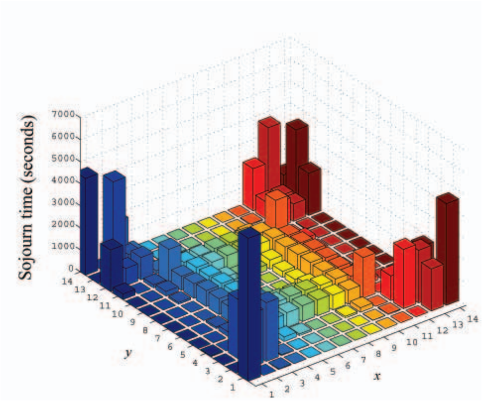

Fig. 8. Sink sojourn times for 14 × 14 networks

$E5$, corresponding to the five periods when the sink sojourns around the four corner areas and the central area, respectively (see Figure 9 below). Within each episode, the sink visits the nodes in the corresponding area according to the solved sojourn times at these nodes.

During the first episode ($E1$), the sink sojourns among the nodes of the first group that are associated with positive sojourn times, i.e., nodes 0, 9, and 17 according to the specific sojourn times at these nodes given in Table II. Then the sink sojourns among the nodes of the second group, i.e., 41, 49, 48, 56, and 57 for the second episode ($E2$) according to the corresponding sojourn times, and so on.

When $E1$ ends we take a snapshot of the residual energy at each node of the network as depicted in Figure 10 below. As expected, nodes closer to node 0 have used more of their initial energies due to the extra burden of receiving and relaying data. Meanwhile, the farther the nodes are from this corner area (nodes 0, 9, 17), the lower is the consumption of their energy.

The residual energy snapshots after episode $E2$, $E3$, $E4$ and $E5$ are displayed in figures from 11 to 14.

Consistently with the previous observation, we see that energy consumption among the network nodes shifts with the sink's motion from one area of the network to the next. A consumption pattern emerges in that the nodes to which the sink pays a visit conserve higher energies compared to most

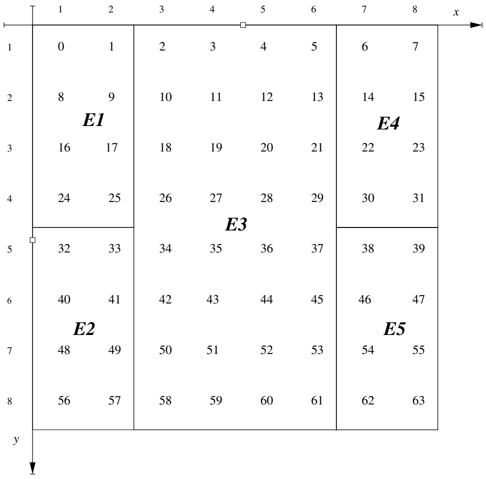

Fig. 9. Sink movement episodes

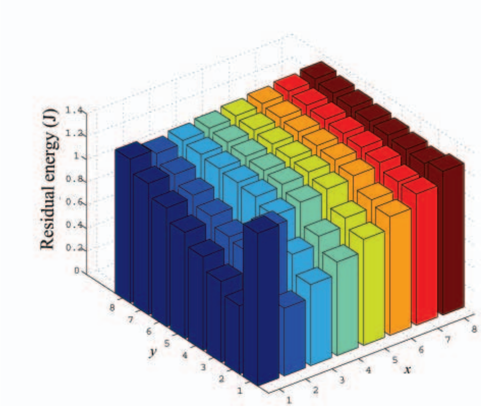

Fig. 10. Residual energy snapshot after episode $E1$

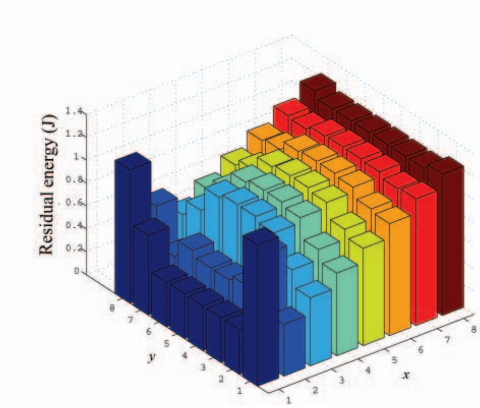

Fig. 11. Residual energy snapshot after episode $E2$

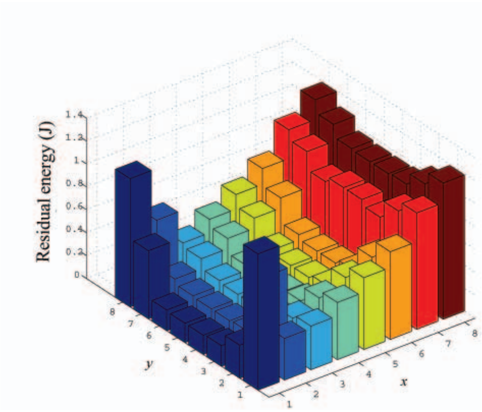

Fig. 12. Residual energy snapshot after episode $E3$

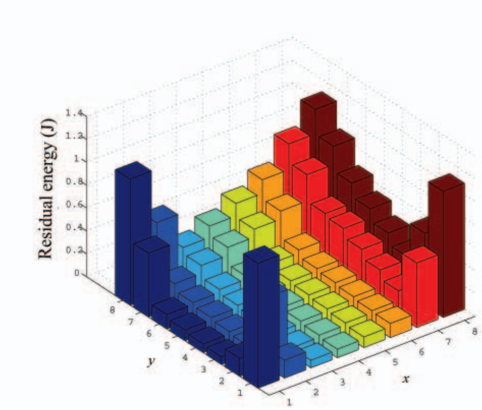

Fig. 13. Residual energy snapshot after episode $E4$

of the others, while their neighbors, i.e., the nodes closest to the sink, suffer the most energy consumption. This is because a node visited by the sink needs to transmit only its own data while its neighbors have to transmit not only their own data but to receive and relay to the sink all other nodes' data. The numerical values of the residual energies after episode $E5$ are also displayed in Table III.

It is remarkable that due to the sink mobility all the nodes except those at the four corner have their initial energies completely depleted at the same time at which the network life ends.

For a comparison, we depict the residual energy snapshots for 8×8 networks with a static sink. By solving (8), we find that the optimal location of the static sink is at one of the four central nodes. The location of the sink at node 27 is examined here. Since the sink is static, the time slices are taken according to the time clock, i.e., the first episode is for the first fifth of the total network lifetime, and the second episode is for the second fifth of the total network lifetime, and so on.

Figures 15 through 19 show that the energy is not evenly consumed among network nodes. The nodes on the two central cross lines are depleted much faster since they take on the role of "backbone" with the sink staying in the center, while most of the other nodes keep their energies. Network lifetime

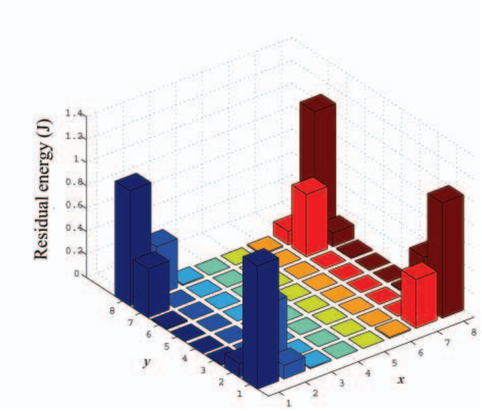

Fig. 14. Residual energy snapshot after episode $E5$

TABLE III

RESIDUAL ENERGY AT THE NODES OF A 8×8 NETWORK AT THE END OF ITS LIFETIME

1.072	0.118	0.010	0.000	0.000	0.010	0.424	1.003
0.118	0.543	0.000	0.000	0.000	0.000	0.000	0.424
0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.010
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.010
0.424	0.000	0.000	0.000	0.000	0.000	0.543	0.118
1.003	0.424	0.010	0.000	0.000	0.010	0.118	1.072

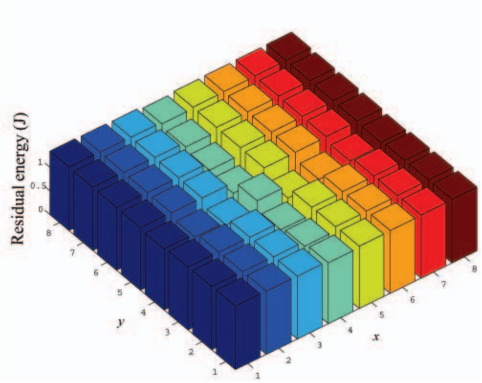

Fig. 15. Residual energy snapshot after episode $E1$ with a static sink

TABLE IV

RESIDUAL ENERGIES OF THE 8×8 NETWORK NODES. THE SINK IS STATIC

1.31	1.27	1.23	1.04	1.20	1.23	1.27	1.31
1.27	1.23	1.20	0.69	1.16	1.20	1.23	1.27
1.23	1.20	1.16	0.35	1.12	1.16	1.20	1.23
1.04	0.69	0.35	**1.31**	0.00	0.35	0.69	1.04
1.20	1.16	1.12	0.00	1.08	1.12	1.16	1.20
1.23	1.20	1.16	0.35	1.12	1.16	1.20	1.23
1.27	1.23	1.20	0.69	1.16	1.20	1.23	1.27
1.31	1.27	1.23	1.04	1.20	1.23	1.27	1.31

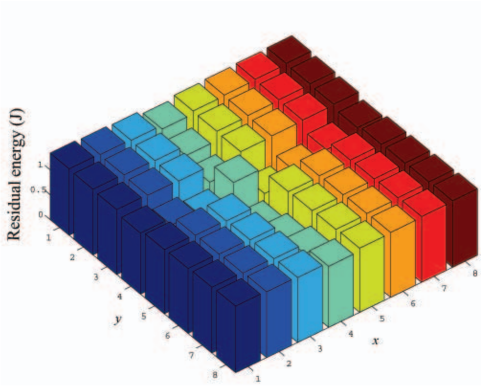

Fig. 16. Residual energy snapshot after episode $E2$ with a static sink

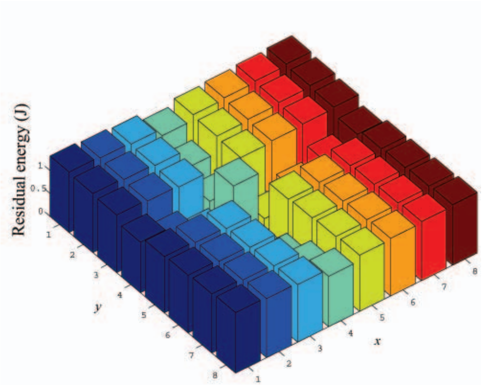

Fig. 18. Residual energy snapshot after episode $E4$ with a static sink

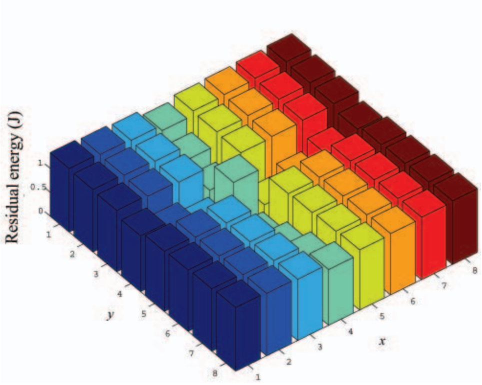

Fig. 17. Residual energy snapshot after episode $E3$ with a static sink

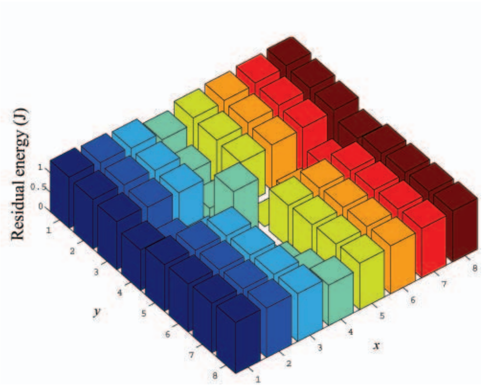

Fig. 19. Residual energy snapshot after episode $E5$ with a static sink

is therefore defined by a small portion of the nodes (only two in this case) that have depleted their energies. Table IV indicates that the two nodes (with highlighted zeros as residual energies), closest to the sink (the central node with boldface 1.31 as its residual energy), bring the network lifetime to its end while the majority of the network nodes still possess between 26% and 97% of their initial energies.

We conclude that by exploiting a mobile sink, and selecting the sink movement according to the solution to our model, network energy is more balanced among the network nodes and data flow bottlenecks can be more effectively avoided, thus improving the overall network lifetime (up to over a 450% increase over the static sink case in networks with 256 nodes).

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we propose a method for using a mobile sink to increase network lifetime. We use a linear optimization model to determine which nodes should be visited by the sink and for how long in order to maximize the time till the first node in the network dies because of energy depletion. Our model directly aims at maximizing network lifetime instead of reducing total energy consumption during data communication, which is what was done in previous solutions. It is demonstrated that almost 500% improvement in network lifetime can be achieved by deploying a sink that moves according to the patterns provided by our model instead of using a static sink. The network energy consumption over time is also studied, which helps validating the effectiveness of the proposed method.

Encouraged by the current results we propose future research that considers more complex circumstances. In particular, the model and the experiments will consider more realistic assumptions which include random data generation rates, data generation rates based on moving targets, multiple mobile sinks and random network topologies. In addition, we will investigate the impact of mobile sinks on network performance such as latency and bandwidth usage.

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