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Delay Bound Trajectory Formulation For Multiple Mobile Sink

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***Abstract*:** *Sink mobility have emerged as the great potential to solve the hotspot problem in the field of wireless sensor networks (WSNs). However, the use of single mobile sink (MS) in a delay-bound network can only delay the problem and is unable to solve it. The solution to the problem is to use multiple MS. In this work, we first estimate the optimal number of MSs required for data gathering within delay limit. Later, an effective data gathering approach is proposed by designing an efficient path for the mobile sinks that visit certain points known as rendezvous points (RPs) to collect data from the sensor nodes. Irrespective to the existing techniques, we have also considered the sojourn time, which is the amount of time for which a MS stays at an RP to collect data. This in turn increases the approximation of the solution. The proposed algorithm is rigorously simulated and compared with an existing algorithm, WRP over various performance metrics like network lifetime, energy consumption, total number of RPs employed etc.*

Keywords: *graph, indegree, k-means, mobile sink, Wireless sensor networks.*

1. Introduction

Data sensing is one the emerging technology that leads to an efficient parametric wireless communication. Wireless sensor network (WSN) is the network that focusses on data sensing and consists of a set of tiny sensor nodes (SNs) having a small computing device, memory, battery and transceiver [1-3]. It has a very wide range of application such as in the military, in agriculture, in the environment, in monitoring health care, etc. It is equally efficient at some places where human intervention becomes difficult. In such areas, sensor nodes sense the event and forwards the sensed information to the sink in a single or multi-hop fashion for further communication [4].

Delivering data to a static sink requires a multi-hop communication among sensor nodes. The nodes which are closest to the sink tends to drain or deplete their energy faster than those which are further away as they are busier in relaying data than data sensing. This scenario is known as a hot-spot problem which further results in loss of connectivity between sink and rest of the network [5,6].

To alleviate this problem, mobile sink (MS) or mobile data collectors are introduced. Here, the sink is in the form of robot or a vehicle which move around the network for data collection from sensor nodes. This further enhances the network lifetime by removing the uneven energy depletion. Visiting each sensor node by MS to collect their sensed data will lead to a very long path. This will cause data starvation at the SNs waiting for MS hence, leads to data loss due to buffer overflow at SNs. Therefore, without any effective path design for mobile sink, the network performance is highly affected [7-12].

In order to remove this problem sink should visit a minimum number of nodes known as RPs. In this work, we have proposed RPs based path design for multiple mobile sink. We have also considered sojourn time factor for deciding the number of mobile sinks. The paper is summarized as follows: Initially, rendezvous points (RPs) are determined by considering center of the star graph as one of the RPs. These are the points where mobile sink will stay to collect the gathered data by that RPs. After the selection of RPs, the numbers of mobile sinks are decided by considering sojourn time factor. The whole network area is partitioned into number of mobile sinks and the path for mobile sink is designed for each partition. The proposed approach focusses on data routing performed by single hop only.

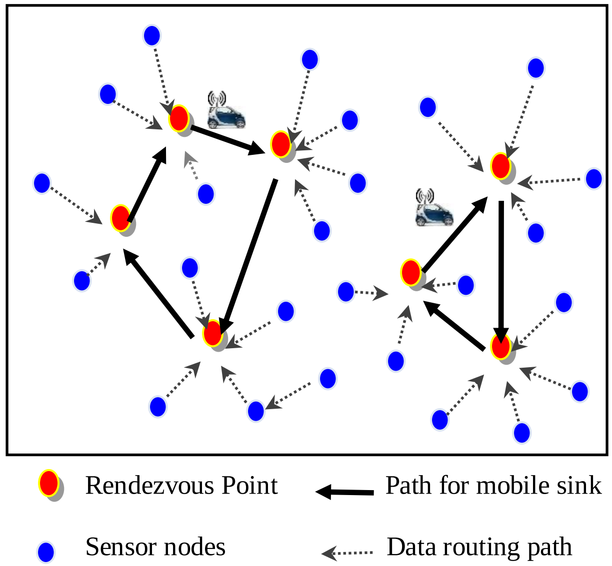

Fig.1: A model for multiple mobile sink based wireless sensor network

The rest of the paper is organized as follows. Section 2 presents the background work related to mobile sink and its related issues. The system model considered for the implementation of the proposal is discussed in Section 3. The proposed approach for path design of mobile sink is modelled in Section 4. The simulation based comparison and performance evaluation of the proposed method is discussed in Section 5. Finally, Section 6 concludes the paper.

2. Related Works

For the past few years, researchers have aspired to remove the hotspot problem through the mobile sink [13][14][15][16]. The sink mobility can be categorized into three groups [17] namely, (i) random mobility, (ii) predictable mobility and (iii) controlled mobility. These different types of mobility define different types of data collection protocols used in each case. Some degree based and energy efficient path design for mobile sink are already introduced in [6-12]. In [18], Data MULEs, a random mobility based technique is used to gather aggregated data. In the similar fashion [19], to collect the data of SNs, flying sink are used which flies over the target area. In random mobility technique, some problems may arise like buffer overflow and latency in data delivery. Authors in [20] present predictable mobility where each sensor node already knows the path followed by the mobile sink and to save energy, SNs turn into sleep mode until their chance arrive. Gao et.al [21] modeled the use of controlled mobility to propose data gathering technique known as maximum amount shortest path (MASP) for enhancing the network life time. In [22], sink mobility is considered by estimating the best position for a mobile sink in the area of interest. The demerits of this approach were their presumption that the paths were already determined, and ignorance of the roaming time of mobile sink on its path. Somasundara et.al [23] have also used the controlled mobility technique, based on the fact that mobile sink will visit each sensor node and a path for the mobile sink is formulated as mobile element scheduling (MES) problem. The major drawback of this work is the increased latency in the data collection process.

In the proposed work, we attempt to generate an efficient path for multiple mobile sink by considering the sojourn time of each node to cover all SNs through one hop communication by any RPs.

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3. System Model

In this paper we have assumed a homogenous WSN which consists of some randomly deployed static sensor nodes and multiple mobile sink. The multiple mobile sink is considered with an unrestricted amount of energy and visit their own set of RPs to collect the sensed data. A SN can communicate with any mobile sink through any one of the RPs. Replacement of sensor nodes is not considered in our approach.

Also, a SN is considered to be dead iff its power supply exhaust completely. We use some notations which are used during the presentation of the proposed algorithm and are listed below in Table 1.

TABLE I: Notation Used

Notation	**Description**
S	$\{s_1, s_2\ldots s_n\}$: *Set of sensor nodes*
RPs	$\{rp_1, rp_2, ---, rp_k\}$: *Set of RPs*
K	*Number of mobile sink*
N	*Total number of node*
R	*Communication Range*
L	*Length of data packets*
Bw	*Bandwidth*
Ted	*Expected Delay for mobile sink*
Tcst	*Cumulative sojourn Time*
Ttd	*Total delay*
PL	*Path length*
E	*Edges of the graph*
Tst	*Sojourn time of a node*

The assumptions regarding the energy model are as follows. The energy requirement for data transfer for any SN is presented by equation (1), which is similar to the energy model used in [25]. There are two variants for energy expense namely, free space (f_s) and multipath (m_p). Free space is used if the communication distance (d) is less than a threshold distance (d_t), otherwise the multipath format is adopted. Assume E_{circ} as the energy required by electronic circuit, ξ_{fs} be the energy needed by amplifier in free space and ξ_{mp} be the energy needed by amplifier in multipath, then the energy required to transmit k-bits over a distance d is given as follows.

$$E_T(k,d) = \begin{cases} kE_{circ} + k\xi_{fs} d^2 & \text{for } d < d_t \\ kE_{circ} + k\xi_{mp} d^4 & \text{for } d \geq d_t \end{cases} \quad (1)$$

This is an anlytical model and hence, the simulation result may differ from the actual ouput. We have used some basic equations for finding the parameters that are used in the proposed algorithm. Equation (2) presents the computation of trasmission time for each data packet for calculating cumulative sojourn time of each RPs .Tramission time is equal to the length of data packets divided by bandwidth of a channel. In equation (3), we are calculating total delay for this network scenario which is the sum of cumulative sojourn time (that is sum of sojourn time of all RPs) and delay provided by a single mobile sink. Finally, the total number of mobile sink is calculated in equation (4).

For Transmission Time,

$$T_{tt} = L/bw \quad (2)$$

For total delay,

$$T_{td} = T_{cst} + PL/v \quad (3)$$

For total number of mobile sink,

$$k = T_{td} / T_{ed} \quad (4)$$

4. Proposed Algorithm

In this paper, we propose an algorithm for the path design of multiple mobile sink. It is RP based path design technique and the algorithmic steps are presented in Fig 2. Initially, we assume that all sensor nodes have potential of becoming RP. Using SNs as vertices, star graphs are formed using the constraint that the distance between two vertices must be less than r. Center of each star graph is considered as one of the RPs. After finding the set of RPs, sojourn time of each RP is calculated by considering transmission delay of each packet of that RP. Sojourn time of each RPs is added for finding cumulative sojourn time. For finding total delay we require two parameters one is cumulative sojourn time which is already calculated and another one is path delay with assuming whole scenario with single mobile sink (that is, path length with single mobile sink divided by speed of the sink). After this we find number of mobile sink by dividing total delay with expected delay. Network is partitioned into different non-overlapping area which is equal to the number of mobile sink by applying K-means algorithm, also the K-means have the parameter distance as well as sojourn time. For each cluster, we will apply TSP for path design. TSP is used to formulate shortest path for mobile sink. If path delay of any cluster is greater than expected delay than the number of mobile sink is incremented by one.

Algorithm : Delay bound based path formulation
Input: set of sensor nodes, *S* and delay S = $\{s_1, s_2, s_3, \ldots, s_n\}$and their positions. ***Output***: Set RP = $\{rp_1, rp_2, rp_3, \ldots, rp_k\}$and path for K-mobile sink. ***Step* 1:** Construct a star graph $G(S, E)$ $\forall$ $E \leq r$. ***Step* 2:** Calculate the indegree of each sensor node and whose *indeg* < 0 selected as RPs ***Step* 2.1:** for i =1 to n do. ***Step* 2.2**: if $indeg_i > 0$ then ***Step* 2.3**: $RPs = RPs \cup S_i$ ***Step* 2.4**: end ***Step* 2.5**:end ***Step* 3:** Find T_{st} for each RPs ***Step* 4:** Find cumulative T_{st} ***Step* 5:** Call TSP(RPs) & find path length ***Step* 6 :** find T_{td} = PL +T_{cst} ***Step* 7:** find $k = T_{td}/T_{ed}$ ***Step* 8 :** Apply K-means for K cluster ***Step* 8.1:** for i = 1 to k do ***Step* 8.2:** RP_i = K-means(C_i; i) ***Step* 8.3:** Call TSP(RP_i) ***Step* 8.4 :** delay = PL_i/v ***Step* 8.5 :** if $delay > T_{ed}$ then ***Step* 8.6 :** $K = K + 1$ ***Step* 8.7 :** goto step 8 ***Step* 8.8 :** end ***Step* 8.9 :**end

Fig. 2: Proposed Delay bound based path formulation

***Lemma*1**: The time complexity of the proposed algorithm takes a time of order of $O(n^3)$.

Proof: Proposed delay bound algorithm is mainly consists of eight steps. In step 1 star graph is formed which will take $O(n^2)$ In step 2 RP is selected which will take linear time i.e $O(n)$. Step 3 and step 4 runs in constant time. In step 5 TSP run over p number of RPs so $O(p^2)$. Step 6 and step 7 runs in constant time. In step 8 TSP runs over m set of RPs in loop of k(number of mobile sink) so $O(kp^2)$.

Therefore, total time complexity $O(n^2)+ O(n)+ O(p^2)+ O(kp^2)$ *i.e* $O(n^3)$ in worst case where all sensor nodes are considered as one of the RPs.

5. Simulation Results

5.1. Simulation Setup

Both the algorithm are simulated rigorously over various network parameters. The initial energy of any sensor nodes is assumed to be 2 J. They become dead if their energy reaches to 0 J. Sink are considered with unlimited amount of energy and having the speed of 2 m/s. The other parameter is same as of [25] and mentioned in Table II. The run time scenario with different number of mobile sink is mentioned here in Fig. 3 with three mobile sink and Fig. 4. with four mobile sink.

TABLE II: Simulation Parameters and Their Values

Parameters	**Values**
Area of interest	220×220 m^2
r	30 to 50 m
n	100
E_{circ}	50*10^9
Data packet size	4000 *bits*
Initial energy of SNs	2J
Delay	300 *sec*
b_w	3000 *bps*

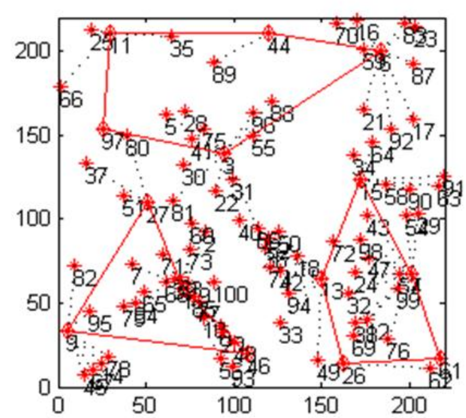

Fig. 3: Simulation instance for 3 mobile sinks

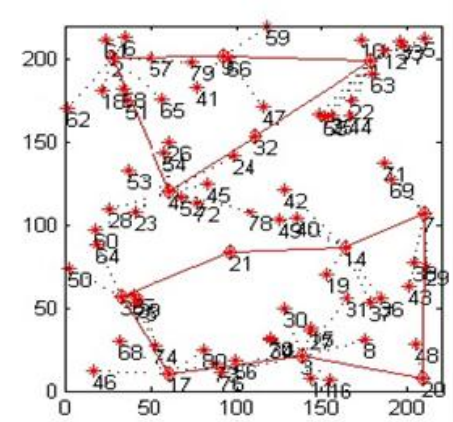

Fig. 4: Simulation instance for 4 mobile sinks

Fig. 3 and Fig. 4 shows the path formation using proposed RP based technique to cover 100 sensor nodes having communication range of 30 m. Here, the network is partitioned into K non-overlapping zone where K is the number of mobile sink. The number of mobile sink changes dynamically based on sojourn time factor. Considering the chances of variation due to random deployment of sensor nodes, the results are evaluated based on the average of ten random simulation. Here, the network is assumed to be dead when one sensor nodes dies.

5.2. Performance Measurement

The performance of proposed scheme is compared with an existing scheme namely WRP [26] in terms of various parameters like hop count, network lifetime and total energy consumption by sensor nodes.

Hop Count:

Hop count is one of the important parameter to measure the effectiveness of any algorithm because it is inversely proportional to the factor of energy consumption among the nodes. Therefore, it is preferable to have hop count as least as possible. Both the algorithms are simulated in terms of hop count with varying number of sensor nodes and varying communication range. In the proposed algorithm, all the sensor nodes are covered by any one of the RPs by single hop only, therefore it gives far better result than the existing algorithm which are presented in Fig. 5 and Fig. 6.

Network Lifetime:

The purpose of introducing multiple mobile sink is to enhance the network life time. So the maximization of network life time is always preferred. Hence, both the algorithm are simulated in same network scenario to measure the network lifetime which is plotted in Fig. 7 with varying number of sensor nodes and Fig. 8 with varying communication range. The results clearly prove that the delay bound based algorithm gives longer lifetime than that of existing one.

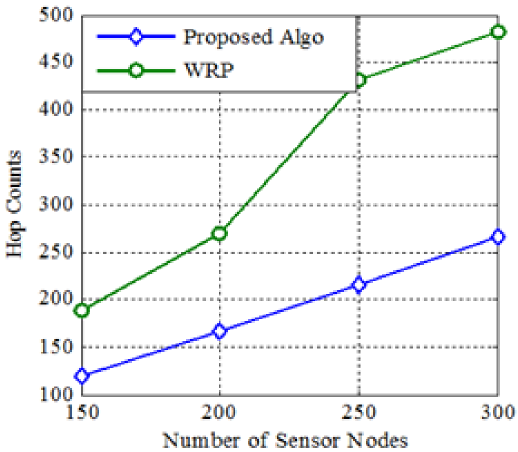

Fig. 5: Comparison for total hop counts for varying node density

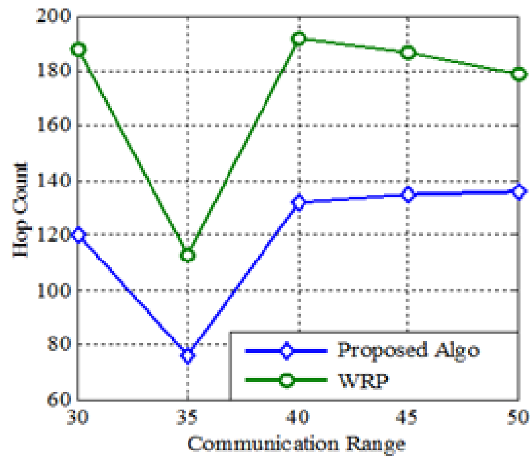

Fig.6: Comparison for total hop counts vs communication range

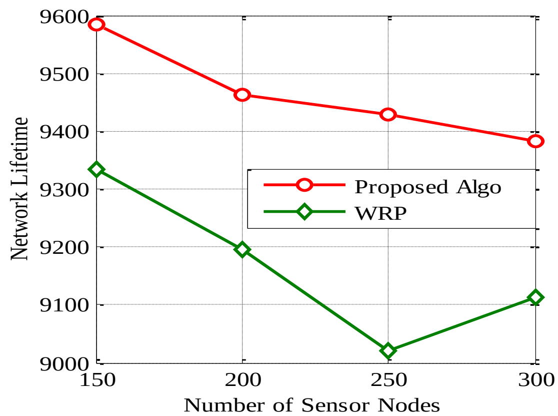

Fig. 7: Comparison for Network Lifetime for varying node density

Energy consumption:

We also simulated both the algorithm for energy consumption and standard deviation for starting 4000 rounds are plotted in Fig. 9 and Fig. 10.

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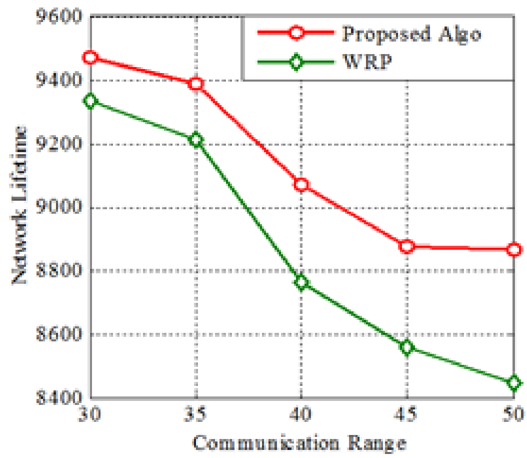

Fig. 8. Comparison for Network Lifetime vs communication range

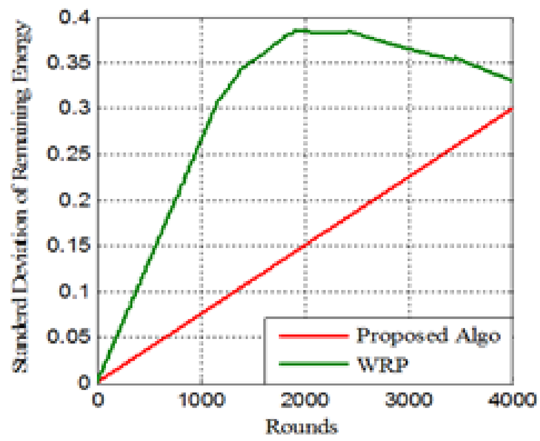

Fig. 9: Comparison for standard deviation of remaining energy of SNs

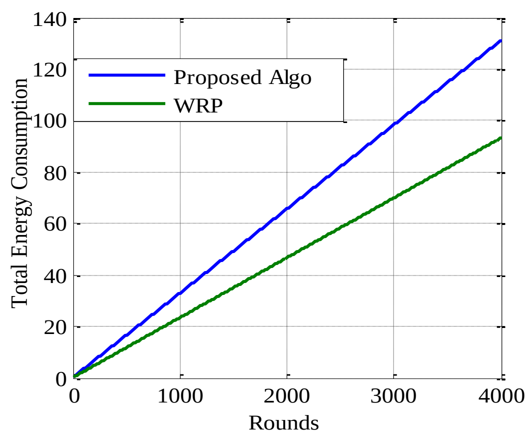

Fig. 10: Comparison for total energy consumption.

6. Conclusion

In this paper, we have proposed a delay-bound path design for multiple mobile sink by considering the sojourn time factor for deciding the number of mobile sinks. The approach will lead to the reduction in the waiting time for SN to transmit data and increase the network performance. Initially, rendezvous points (RPs) are determined by considering center of the star graph as one of the RPs. These are the specific points where mobile sink will stay to collect the gathered data by that RPs. After the selection of RPs, the numbers of mobile sinks are decided by considering sojourn time factor which is the time duration for which a MS stays at an RP to collect data. The whole network area is partitioned into number of mobile sinks and the path for mobile sink is designed for each partition. The proposed algorithm is rigorously simulated and compared with an existing algorithm, WRP over various performance metrics like network lifetime, energy consumption, total number of RPs employed etc. The simulation results show that the proposed delay bound path design for mobile sink outperforms than the existing algorithm.

7. References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless sensor networks: a survey," *Comput. Networks*, pp. 393–422, 2002.

[2] R. Jaichandran, and J. E. Raja , "Effective strategies and optimal solutions for Hot Spot Problem in wireless sensor networks (WSN)," *in Proc. 10th International Conference on Information Sciences Signal Processing and their Applications (ISSPA)*, pp. 389-392, May 2010.

[3] S. Olariu, & I. Stojmenovic, "Design Guidelines for Maximizing Lifetime and Avoiding Energy Holes in Sensor Networks with Uniform Distribution and Uniform Reporting," *in Proc. INFOCOM*, pp. 1-12, April 2006.

[4] G. Xing, T. Wang, Z. Xie, and W. Jia, "Rendezvous planning in wireless sensor networks with mobile elements," *IEEE Trans. Mobile Computing*, vol. 7, no. 12, pp. 1430-1443, December 2008.

[5] J. A. Hartigan and M. A. Wong, "Algorithm AS 136: A k-means clustering algorithm," *Applied Statistics*, vol. 28, no. 1, pp. 100-108, 1979.

[6] K. Nitesh and P. K. Jana, "Dfda: a distributed fault detection algorithm in two tier wireless sensor networks," in *Proc. 3rd Int. Conf. Frontiers of Intelligent Computing: Theory and Applications (FICTA)*, pp. 739-746, 2015.

[7] P. Komal, K. Nitesh and P. K Jana, "Indegree-based path design for mobile sink in wireless sensor networks," in *Proc. 3rd International Conference on Recent Advances in Information Technology (RAIT)*, pp. 78-82, 2016.

[8] M. Mishra, K. Nitesh and P. K. Jana, "A delay-bound efficient path design algorithm for mobile sink in wireless sensor networks," in *Proc. 3rd Int. Conf. Recent Advances in Information Technology (RAIT)*, pp. 72-77, 2016.

[9] A. Kaswan, K. Nitesh and P. K. Jana, "Energy efficient path selection for mobile sink and data gathering in wireless sensor networks," AEU-International Journal of Electronics and Communications, vol. 73, pp. 110-118, March 2017.

[10] A. Kaswan, K. Nitesh and P. K. Jana, "A routing load balanced trajectory design for mobile sink in wireless sensor networks," in *Proc. Int. Conf. Advances in Computing, Communications and Informatics (ICACCI)*, pp. 1669-1673, September 2016.

[11] K. Nitesh, Md. Azharuddin and P. K. Jana, "Minimum spanning tree–based delay-aware mobile sink traversal in wireless sensor networks," *Int. J. Communication Systems*, January 2017, DOI: 10.1002/dac.3270.

[12] K. Nitesh, Md. Azharuddin and P. K. Jana, "A novel approach for designing delay efficient path for mobile sink in wireless sensor networks," *Wireless Networks*, pp. 1-20, February 2017.

[13] J. Luo and J. P. Hubaux, "Joint sink mobility and routing to increase the lifetime of wireless sensor networks: the case of constrained mobility," *IEEE/ACM Trans. Networking*, vol. 18, no.3, pp. 871-884, June 2010.

[14] S. Jain, R.C. Shah, W. Brunette, G. Borriello and S. Roy, "Exploiting mobility for energy efficient data collection in sensor networks," *Mobile Networks Appl*. vol. 11, no. 3, pp. 327–339, 2006.

[15] A. Chakrabarti et al., "Communication power optimization in a sensor network with a path-constrained mobile observer," *ACM Trans. Sensor Networks*, vol. 2, no. 3, pp. 297–324, 2006.

[16] E. Guney et al., "Efficient integer programming formulations for optimum sink location and routing in heterogeneous wireless sensor networks," *Comput. Networks*, 2010.

[17] C. Ioannis, K. Athanasios and N. Sotiris, "Sink mobility protocols for data collection in wireless sensor networks," in *Proc. 4th ACM international workshop on mobility management and wireless access, MobiWac*, pp. 52–59, New York 2006.

[18] R.C. Shah, R.C., et al, W., "Data MULEs: modeling a three-tier architecture for sparse sensor networks," in *IEEE Workshop on Sensor Network Protocols and Applications (SNPA)*, pp. 30–41, 2003.

[19] L. Tong, Q. Zhao, S. Adireddy, "Sensor networks with mobile agents," in *Proc. IEEE Military Communications Conference (MILCOM)*, vol. 22, pp. 688–693, Boston, October 2003.

[20] A. Chakrabarti, A. Sabharwal, B. Aazhang, "Using predictable observer mobility for power efficient design of sensor networks," in *Proc. 2nd international conference on information processing in sensor networks, IPSN, Heidelberg: Springer-Verlag*; pp. 129–145, 2003, Berlin.

[21] G. Shuai, Z. Hongke, S. K. Das, "Efficient data collection in wireless sensor networks with path-constrained mobile sinks," *IEEE Trans Mob Comput*, vol. 10, no. 4, pp. 592–608, April 2011.

[22] Y. Shi and Y.T. Hou, "Theoretical results on base station movement problem for sensor network," in *Proc. 27th Conference on Computer Communications, IEEE INFOCOM,* April 2008.

[23] A. A. Somasundara, A. Ramamoorthy, M. B. Srivastava, "Mobile element scheduling with dynamic deadlines," *IEEE Trans Mob Comput*, vol. 6, no. 4, pp. 395–410, April 2007.

[24] G. Xing, M. Li, T. Wang, W. Jia and J. Huang, "Efficient rendezvous algorithms for mobility-enabled wireless sensor networks," *IEEE Trans. Mobile Comput*, vol. 11, no. 1, pp. 47–60, January 2012.

[25] Y. Shi and Y. T. Hou, "Optimal base station placement in wireless sensor networks," *ACM Trans. Sensor Networks*, vol. 5, no. 4, article no. 32, November 2009.

[26] H. Salarian, K. W. Chin, and F. Naghdy, "An energyefficient mobile-sink path selection strategy for wireless sensor networks," *IEEE Transactions on Vehicular Technology*, vol. 63, no. 5, pp.2407–2419, 2014.