Handling Sink and Object Mobility in Wireless Sensor Networks

Kulwardhan Singh* and T. P. Sharma**
*National Institute of Technology Hamirpur, India
kulwardhan@yahoo.com
**National Institute of Technology Hamirpur, India
teekparval@gmail.com

Abstract: The rapid progress of wireless communication and embedded micro-sensing MEMS technologies enable the wireless sensor networks (WSN) offer many new possibilities for applications such as remote monitoring objects and environmental surveillance by allowing the sink/user to move around freely. However, monitoring mobile objects and disseminating sensing data to the mobile sink raises significant design challenges for the routing scheme. In addition, limited power supply of sensor nodes and therefore reducing energy consumption in order to prolong the lifetime of the WSN is another challenge. In this paper, in order to monitor the mobile objects and disseminates the data to mobile sinks, we propose a routing scheme for Handling Sink and Object Mobility (HSOM) in Wireless Sensor Networks, which is energy efficient and has minimum rerouting frequency. Analytical and simulation study reveals significant improvement over the existing schemes.

Keywords: Wireless Sensor Network (WSN), Sink Mobility, Object Monitoring, Energy Efficient.

Introduction

The Wireless Sensor Networks (WSNs) are made up of wireless nodes endowed with sensing capabilities that are deployed for implementing a host of different applications. Wireless sensor networks (WSNs) are widely used in many industrial and civilian application areas, including industrial process monitoring and control, machine status monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control. Typically, a large number of tiny sensor devices called motes constitute a WSN, where motes are considered as constrained in resources, such as limited on-board memory, short-range radio transceivers and limited battery power. These sensor nodes form a decentralized, multi-hop, self-organized network system. Depending on the application environment, nodes are interfaced with various sensors for monitoring some phenomenon of interest (temperature, humidity, pressure, etc.) and forward the stimulus data to the data centres (Sinks) through multi-hop communication [1]. To prolong network lifetime, minimizing the energy consumption of individual sensor nodes is important, as well as balanced energy consumption among all the sensor nodes is also desired.

Monitoring the mobile objects is one of the most important areas where the advantages of wireless sensor networks can be exploited. These networks may be deployed for the application in military for tracking enemy vehicles, detecting illegal border crossings as well as in civilian for monitoring the movement of wild animals in wildlife preserves [2][3]. Object monitoring consists of detecting and monitoring locations of real-world objects, using several types of sensing such as acoustic, seismic, electromagnetic, etc. WSN can have one or multiple sinks that sends query or control commands to the sensor node and collect the information from the sensor node(s). In traditional WSNs, sensor nodes are distributed in the sensing field whereupon detecting some event of interest, nodes report the sensed event back to some static sink(s) through single-hop or multi-hop communication. One major drawback of such communication infrastructures is occurrence of hot-spot or sink-hole problem in the neighborhood of the sink(s). This is because sensor nodes close to the static sink will consume more energy and thus their energy will deplete quickly. To overcome hot-spot or sink-hole problem, the concept of mobile sink was introduced in WSN [4], that not only results in balanced energy consumption among the nodes but can also be exploited to connect isolated segments of the network. The mobile sink(s) are more energy efficient than the static, but has the additional overhead such as sink's location maintenance, continuous data delivery and dynamic route adjustments with sink mobility [5][6]. There are various routing protocols proposed for WSN in order to deal efficiently with the sink mobility [7,8,9]. The mobile sink has the multifold advantages like hotspot problem removal, energy efficient, longer network lifetime etc., but also include new challenges such as sink location management and dynamic route adjustments.

There are many protocols developed for WSN, which support the mobile sink(s) such as Directed Diffusion [10], GEAR[11], GBR [12]. These protocols maintain the location of the mobile sink by continuously propagating the location of the sink throughout the sensor network, so that all sensor nodes are updated with the recent location of the sink(s). But frequent updating cause traffic increase in WSN, collision in wireless transmission and more power consumption. TTDD[13] provides two disseminating tiers for large-scale sensor networks with multiple mobile sinks. TTDD architecture exploits the fact that the sensor nodes are stationary and are location aware and queries of multiple mobile sinks are confined within the local only. In TTDD, on event detection each source node proactively constructs a grid throughout the sensor field, so that, only sensors located at the grid points need to acquire the sensing information. However, when multiple events occur sensed by multiple nodes, each node proactively constructs its own grid structure, due to which communication and storage overhead of TTDD architecture increases. Therefore, as number of sources increases, the data dissemination point management overhead increases considerably. Similarly, ALS [14] protocols also uses the virtual grid structure to find the location of mobile sinks. ALS is a grid based protocol that provides sink location information in a scalable and efficient manner. In ALS, the sink agent distribute the location information of the sink using anchor system in four straight orthogonal directions (North, South, East, West) and all the grid nodes that lie along the routing path are recruited as anchor which acts as location server. On occurrence of an event, the source node will register itself with the nearest grid node, which is known as the source agent. The source agent will send four query packets in orthogonal directions to find the location of the sink agent. Once the source agent receives the sink agent's point location, it forwards it to the source, which finally sends the data packets to the sink agent using the GPSR protocol [15]. This protocol has some drawbacks such as source can't identify the location of the sink if it has not constructed the anchor system, detour problem occurs when sink has high mobility, hotspot problem for border nodes because ALS always uses its border nodes when it provides its sink location. Tsai H. et al. proposed Dynamic Object Tracking (DOT) protocol [20] for sensor networks in 2007, which concentrate on the mobile users how to query target tracks and obtain the target position effectively. This protocol guides a mobile user to chase a mobile object and avoid flooding to obtain the present location of the object. In this protocol the mobile user will catch the target along the sequence of beacon sensor nodes. As the target of moving arbitrarily, therefore, track rout never be a straight line. Thus the mobile user never catches the mobile target having velocity more than mobile user. E. Lee et al. proposed IGS [16] in 2011, which exploits a k-level Independent Grid Structure (IGS) for data dissemination from sources detecting the events to sinks. This protocol supports the scalability and mobility against sinks and events in wireless sensor networks. Sources are required to send event reports to grid header in the inner most layer of IGS and sinks can send queries to grid headers in IGS to request event reports. The grid head aggregates report packets of the same event and makes an aggregated report packet. Then, the grid head disseminates the aggregated report packet to its higher level grid head and this process continues till report packets reach at the inner most grid head (i.e. 1-level grid head).

In this paper, we propose a routing scheme for Handling sink and object Mobility (HSOM) in Wireless Sensor Networks, which is a grid-based routing to monitors the mobile objects and disseminates the data to the mobile sinks. In this scheme, the grid is constructed by the sink appearing first in the sensor field or when no valid grid exists. The Grid Nodes (GNs) are used to forward the data/query between source and mobile sink. A node become the source upon detection of an object and report the attributes of the object to the nearest GN called Source Grid Node (SGN). The SGN initiate the path setup message to sink as well as sends the object appearance message to its all neighboring nodes. This will help to continuous monitoring of object while moving across the cells in sensor network. In this scheme, SGN sends the updated location of the object to the sink. Thus sink maintains the complete route map of the object mobility. As object is always in the periphery of SGN, the sink can reach to the target through straight line instead of following the arbitrary path. This scheme handles the mobility of sink efficiently and has the ability to modify partial or full path to avoid detour problem.

Rest of the paper is organized as follows. Section 2 describes the grid construction, object detection, object monitoring and sink mobility. In section 3, performance of the (HSOM) is evaluated. Section 4 concludes the work.

Handling Sink and Object Mobility (HSOM)

The basic assumption considered for HSOM protocol are mentioned below:

- The sensor field is represented as a two-dimensional plane constructed along x-axis and y-axis and divided into equal sized cells.
- The sensor nodes are randomly deployed in two dimensional square field. The Sensor nodes remain stationary and aware of their geographical location using GPS system or localization algorithm [18].
- Data/query is disseminated using single-hop or multi-hop communication.
- HSOM uses the grid that is constructed by the sink appearing first in the sensor field or when no valid grid exists. All other sources and sinks appear thereafter use the same existing grid.
- Each sensor node is aware of its available energy. One or more mobile sinks are deployed in the sensor field to gather data.
- Objects appear field are wondering across the sensor field.

Grid Construction

In HSOM scheme, the grid construction is initiated by the sink appears first in the sensor field or when no valid grid exists. Sink starts grid construction process by keeping itself at one of crossing point (CP) of the grid with coordinates (X_S, Y_S). The grid is constructed in same way as mentioned in SLDD [17]. The two dimensional geographical coordinates (x, y) of this sink thus become starting point for formation of grid of square sized cells. In this scheme, the node nearest to the CP and within radius r (where r = R/8 and R is the transmission range of a sensor node) from CP is selected as Grid Node (GN). Each GN can communicate with its neighboring GNs in a single hop communication. Thus, in HSOM, the cell size is determined by the radio range of sensor node. As each GN can forward the data to all neighboring GNs in a single hop, therefore, two GNs lying diagonally can't be apart more than their transmission range R. Thus, the cell size α is determined as:

$$\alpha = \frac{3R}{4\sqrt{2}} \tag{1}$$

All other crossing points (CPs) located at P = (X_P, Y_P) are calculated using starting point (X_S, Y_S) and cell size α as:

$$\{X_P = X_S + i * \alpha,\ Y_P = Y_S + j * \alpha;\} \tag{2}$$

$$\text{Where} \quad i, j = \pm 0, \pm 1, \pm 2, \pm 3, \ldots\ldots\}$$

For any GN, all its neighboring GNs are lying within its transmission range. Therefore, it can communicate with its neighboring GNs in a single hop communication.

Object detection process

When an object appears in the sensor field, it is detected by one or more nodes with the cell. This sensor node become the source and sends the report message to the GN that is nearest to the sink called Source Grid Node (SGN). There are chances that the object is detected by one or more sources. All these sources send the stimulated data about the object to the SGN. The SGN aggregates the data if required in order to eliminate the redundant data. The SGN is responsible for path setup and data delivery to sink. The SGN sends the path setup message to upstream GN towards sink, which in turn further forwards the message to its upstream GN towards sink. This process continues till message reaches at the sink as shown in figure 1.

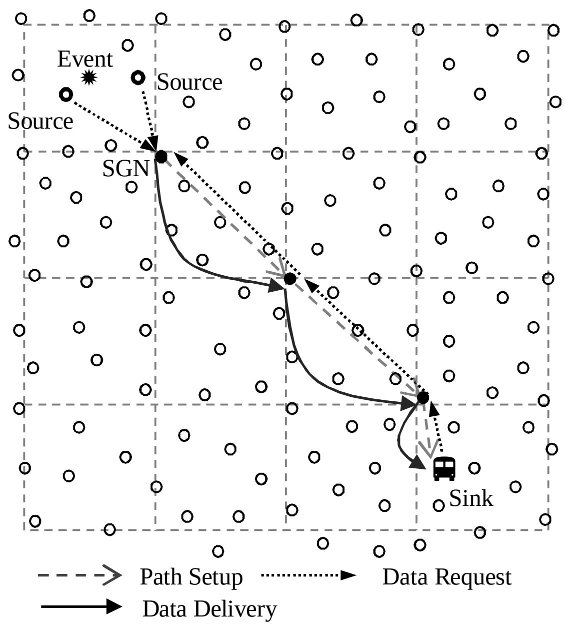

Figure 1. Event Detection and Announcement

Object Monitoring Process

As the object is mobile, there are chances it may go out of site of some source nodes and some new nodes become the sources. These new source nodes send the stimulated data to the SGN. To monitor the moving object continuously, SGN sends the object occurrence message to its all neighboring GNs as shown in figure 2. All these GNs evaluate the data path to the sink in advance to maintain the continuous data delivery. This will help the active SGN to handoff its responsibility to the GN when object enters in its periphery. As the object is moving randomly in the sensor field, therefore, the possibility to selects a GN as new SGN is totally depends upon object mobility. When the object is moving in the cells for which SGN is

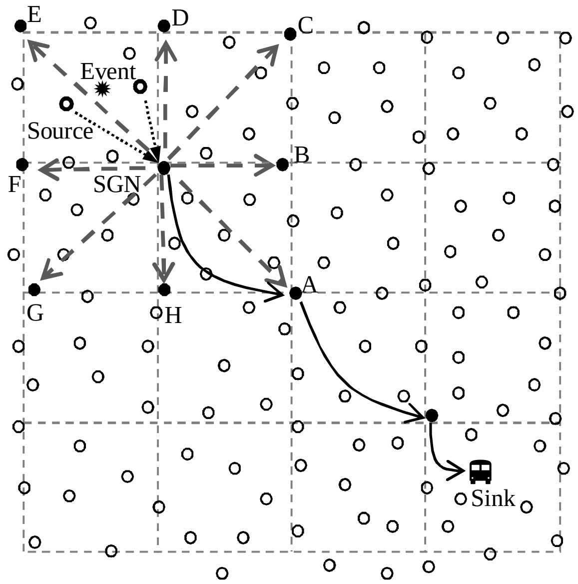

Figure 2. Announcing occurrence of an object to neighbouring GNs

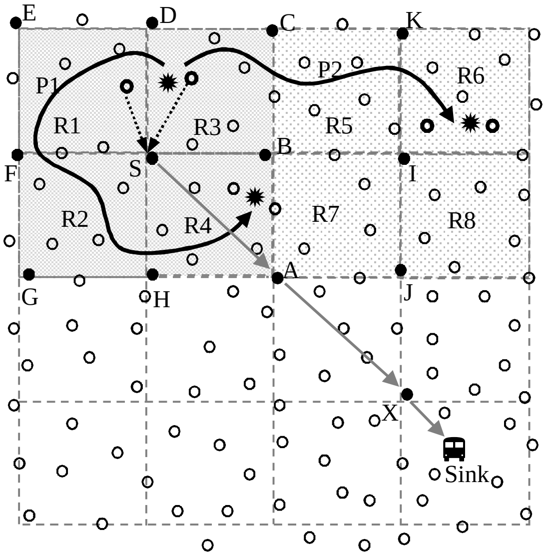

Figure 3. Monitoring object movement and delivering data to sink.

Table 1. Selection of SGN and FN w.r.t. object mobility in different regions

Region in which mobile object enters	GN selected as SGN	Neighbour GN/FN selected for data forwarded
R1	S	A
R2	S	A
R3	S	A
R4	A	X
R5	B	A
R6	I	A
R7	A	X
R8	J	X

common GN, then data is deliver through the same path. As Shown in figure 3, the object is moving along the path P1 over the regions R1, R2, R3 and R4. In this case source grid node 'S' is the common for all these regions. When the object is in the regions R1, R2, R3, the nodes that become the source sends the message to GN 'S'. But when the object is in the region R4, there are two GNs i.e. 'S' and 'A' that are forwarding the data towards the sink. In this case, the node that is nearest to the sink is selected as new SGN. Thus GN 'A' will become the new SGN and all new sources will forwarded the message/data to the newly selected SGN. This SGN then forward the data to sink through same existing path.

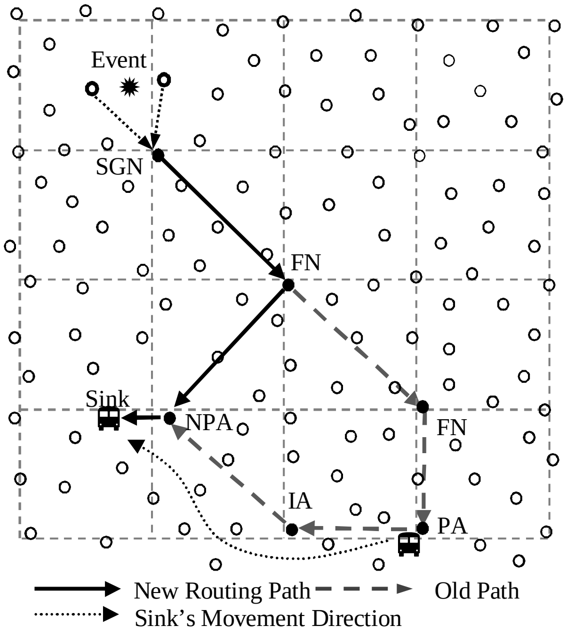

Figure 4. Handling Sink Mobility

When the object moves across the cells where SGN is not common, the alternate GN is selected as new SGN depending upon different scenarios. As Shown in figure 3, the object is moving along the path P2 over the regions R5, R6, R7 and R8. When the object enters in the cell e.g. region R7 where one or more GN is/are acting as SGN or Forwarding Node (FN), then the GN that is nearest to the sink as new SGN (in region R7 the GN 'A' will become the SGN). When object enter in the cell where no GN is acting as SGN/FN, then GN that is nearest to sink and in the neighborhood of previous SGN is selected as new SGN. This new SGN will forward the data to sink through previous SGN or any neighbor FN nearest to sink. Thus depending upon the position of the object as shown in figure 3, the selection of SGN, and the FN through which data is disseminated is summarized in table 1.

Handling Sink Mobility

The proposed HSOM scheme supports the sink and object mobility. Therefore, it is required to monitor the object and maintain the path for continuous data delivery. When sink moves, the node that is nearest initial CP is selected as Primary Agent (PA). PA communicates with the mobile sink while it moves within one hop distance. PA is responsible for receiving the query from the sink and forwards the data to it. When sink moves beyond PA range then it selects the nearest GN as Immediate Agent (IA). If IA is a FN on the existing path, then it become New PA (NPA) and removes the old upstream path from NPA to PA. If IA is not a FN, then it sends a message to its neighbour GNs. If any neighbouring GN is acting as FN on existing path except PA, then IA selects the FN that is nearest to SGN as NPA and removes the upstream path from NPA to PA. Otherwise, IA become NPA and receives the data through old PA. In this situation if NPA also initiates a process to check the detour problem. If NPA discovers the economic path from SGN or intermediate FN, then it initiate new path setup process as shown in figure 4. Once new path is setup, the SGN or FN from where new path is setup, sends path termination message through old path. When NPA receives this message, it stops receiving any more data from PA. This will helps to avoid loss of data flowing through old path.

Performance Analysis

In this section we evaluate the performance of HSOM and compared with some existing schemes such as TTDD and IGS. The performance of HSOM is evaluated by comparing it to TTDD and IGS in terms of in terms of total energy consumption, average delay with varying number of nodes and sinks/event mobility. In this performance evaluation we use the energy model as described by Bhardwaj M. et al. [16]. The key energy parameters are the energy needed to sense a bit (E_{sense}), receive a bit (E_{rx}) and transmit a bit over a distance d (E_{tx}). Assuming path loss in energy model is $1/d\eta$. The default simulation setting has a square sensor field of size 2000 x 2000 m^2 in which 200 sensor nodes are uniformly distributed. Some of these sensor nodes act as sources and generate one data packet per second. Simulation model is run 100 times and the observation is based on the varying numbers of sensor nodes, sink mobility and event mobility. The size of control/query packet is 36 bytes and data packets are 64 bytes. Path loss is set as $\eta = 2$. The transmission range R of each sensor is 100 m and the value of α is evaluated according to equation (1). Table 2 summarizes various simulation parameters.

Effect of node density on total energy consumption and average delay

In this subsection we evaluate the total energy consumption with varying node density. The number of sensor node varies from 200 to 700 and four sinks are moving in the field at a speed of 10 m/s. The total energy consumed by HSOM is less energy as compared to TTDD and IGS as shown in fig 5. It is observed that HSOM consumes 16% and 11% less energy when compared with TTDD and IGS respectively. This is because node density doesn't impact much in case HSOM scheme as the data/query communication through GN only. Also, in HSOM single grid structure is used where as in TTDD one grid per source is constructed and in case of IGS k-level grids are used. The overall delay of HSOM is approximately 18% and 30% less when compared with the TTDD and IGS respectively. This is because HSOM uses the optimal path as it has the ability to modify partial or full path efficiently to avoid any detour problem while sink is mobile.

Effect of sink and event speed on total energy consumption

In this subsection we evaluate the total consumed energy with various sink and event speed. The sink speed is varied from 0, 2, 4, 6, 8 to 10m/s. There are 200 sensor nodes deployed in the field. The total energy consumed by HSOM is considerable less as compared to TTDD and IGS as shown in figure 7. This is because HSOM has the ability to modify partial or full path efficiently to avoid any detour problem. The figure 8 shows the total consumed energy when the speed of object/event is varies from 0, 2, 4, 6, 8 to 10m/s. It is observe that energy consumed by HSOM is approximately 51% and 38% less as compared to TTDD and IGS respectively. This is because HSOM uses single grid structure where as TTDD constructs one grid per source and IGS uses K-level grid structure. Therefore TTDD and IGS consume more energy for constructing and maintaining the grid structure.

Table 2: Simulations parameters

Parameters	Values
Size of Sensor Network	2000 X 2000 m^2
$\propto_1$ ($\propto_1 = \propto_{11} + \propto_{12}$)	180nJ/bit,
$\propto_2$	10pJ/bit/m^2
Data Packet Size	64 Bytes
Query/Control Message Size	36 Bytes
Transmission Range (d)	100 m
Number of Sensor nodes	200
Numbers of Sinks	4
Distribution Type of Sensor Nodes	Uniform

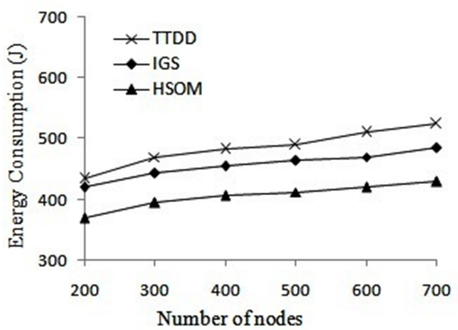

Figure 5. Energy Consumption vs. Node Density

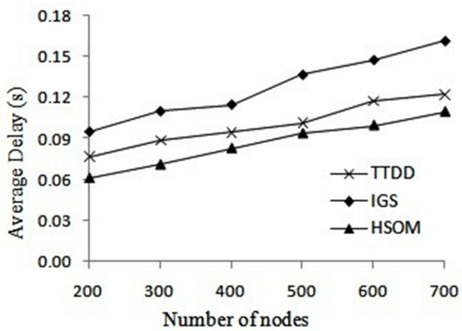

Figure 6. Average Delay vs. Node Density

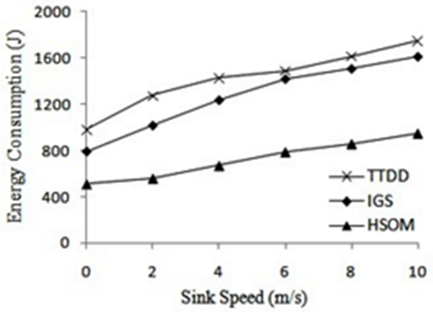

Figure 7. Energy Consumption vs. Sink Speed

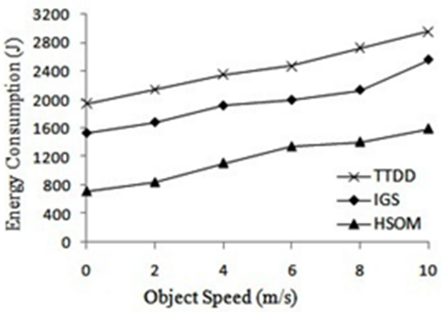

Figure 8. Energy Consumption vs. Object Speed

Conclusion

Proposed routing scheme for Handling Sink and Object Mobility (HSOM) in wireless sensor networks is suitable for scalability and mobility against sinks and events. The HSOM uses the virtual grid structure constructed by the sink appearing first in the sensor field or when there exists no valid grid. The grid nodes are used to disseminate data/query to/from sinks. To monitor the event mobility, Source Grid Node (SGN) sends the announcement message to its neighboring grid nodes (GNs). Each GN evaluates the energy efficient path well in advance. When mobile object enters in the periphery of a GN, it disseminates the data through the path it had evaluated in advance. To handle the sink's mobility, this scheme exploits the location of sink to setup up the shortest path between source and sink. Moreover, HSOM handles mobile sink very efficiently and maintains the path for continuous data delivery. It also construct/update a partial or new path between source and mobile sink if any detour problem occur, thus conserving the sensor nodes energy and increasing the network lifetime. Simulation results also indicate that HSOM consumes less energy and average delay as compared to TTDD and IGS for different numbers of sensor nodes, sinks/event mobility.

References

[1] Al-Karaki J. N. and Kamal A. E. "Routing techniques in wireless sensor networks: a survey", IEEE Wireless Communications, 11(6), 6–28, 2004.

[2] Albert Y. Z., "Handbook of Sensor Networks: Algorithms And Architectures", A John Wiley & Sons, Inc. publication, 2005.

[3] Ramya K., Praveen Kumar K. and Rao V. S., "A Survey on Target Tracking Techniques in Wireless Sensor Networks", International Journal of Computer Science & Engineering Survey (IJCSES) Vol.3, No.4, pp 93-108, August 2012.

[4] Chakrabarti A., Sabharwal A. Aazhang B., "Using Predictable Observer Mobility for Power Efficient Design of Sensor Networks", In Proceedings of the Information Processing in Sensor Networks, (IPSN'03), pp. 129–145, CA, USA, 22–23 April 2003;

[5] Ekici E., Yaoyao G., and Bozdag D. , "Mobility-Based Communication in Wireless Sensor Networks", IEEE Communications Magazine, Vol. 44 issue 7, pp. 56 – 62, July 2006.

[6] Gandham S.R., Dawande M, Prakash R., Venkatesan S., "Energy Efficient Schemes for Wireless Sensor Networks with Multiple Mobile Base Stations", In Proceedings of the IEEE Global Telecommunications Conference 2003 (GLOBECOM'03), pp. 377–381, USA, December 2003.

[7] Hamida E. B. and Chelius G. , "Strategies for data dissemination to Mobile Sinks in Wireless Sensor Networks", IEEE Wireless Communication, Vol. 15 No. 6, pp. 31 – 37, December, 2008.

[8] Faheem Y., Boudjit S., Chen K., "Data Dissemination Strategies in Mobile Sink Wireless Sensor Networks". IEEE 2nd Wireless Days Conference, France, pp. 1 – 6, December 2009.

[9] Pantazis N. A., Nikolidakis S. A., and Vergados D. D.; "Energy-efficient routing protocols in wireless sensor networks: A survey"; Communications Surveys & Tutorials, IEEE, Vol.-15, Issue- 2, pp 551-591, May 2013.

[10] Intanagonwiwat C., Govindan R. and Estrin D., "Directed Diffusion: a Scalable and Robust Communication Paradigm for Sensor Networks", ACM International Conference on Mobile Computing & Networking (MobiCom'00), Boston, MA, pp. 56–67, 2000.

[11] Yu Y., Estrin D. and Govindan R., "Geographical and Energy-Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks", UCLA Computer Science Department Technical Report, UCLA-CSD TR-01-0023, May 2001.

[12] Schurgers C. and Srivastava M. B., "Energy Efficient Routing in Wireless Sensor Networks", MILCOM Proceedings Communications for Network-Centric Operations: Creating the Information Force, McLean, VA, 2001.

[13] Luo H., Ye F., Cheng J., Lu S. and Zhang L., "TTDD: Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks", Springer, Wireless Networks, Vol. 11, pp. 161–175, 2005.

[14] Zang R., Zhao H. and Labrador M., "The Anchor Location Service (ALS) Protocol for Large-scale Wireless Sensor Networks" ACM Proceedings of the First International Conference on Integrated Internet Ad hoc and Sensor Networks, article no. 18, France, May 2006.

[15] Brad Karp and Kung H. T., "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks", In Mobicom proceedings of the 6th annual international conference on Mobile computing and networking, NY, USA, pp. 243 – 254, August 2000.

[16] Lee E. et al. , "Data Dissemination Protocol based on Independent Grid Structure in Wireless Sensor Networks", 22 International symposium on Parallel, indoor and Mobile Radio Communication, Toronto, 11-14 Sept. 2011.

[17] Singh K., Sharma T.P. , "Sink Location-Oriented Data Dissemination using Grid in Wireless Sensor Networks," Elsevier Science and Technology, pp. 346-353, 2013.

[18] Han G., Xu H., Duong T. Q., Jiang J., Hara T., "Localization algorithms of Wireless Sensor Networks: a survey", Springer Telecommunication Systems, Volume 52, Issue 4, pp 2419-2436, April 2013.

[19] Bhardwaj M., Garnett T., Chandrakasan A. P., "Upper bonds on the Lifetime of Sensor Networks", IEEE Conference on Communications (ICC 2001), Finland, , Vol. 3, pp 785 – 890, June 2001.

[20] Tsai H. et al., "Mobile Object Tracking in Wireless Sensor Networks", Science Direct, Computer Communications, volume 30, Issue 8, pp. 1811 – 1825, 2007.