

Energy Efficient Communication Protocol for Wireless Sensor Networks with Mobile Node

Hiren Kumar Deva Sarma

Department of IT

Sikkim Manipal Institute of Technology,
Majitar, Sikkim, India,

PIN-737136

Prativa Rai

Department of IT

Sikkim Manipal Institute of Technology,
Majitar, Sikkim, India,

PIN-737136

Bhupesh Deka

Infosys Ltd

Bhubaneswar, India, PIN-75102

Abstract—Wireless Sensor Networks have become hot research stuff in the current age. This field has got tremendous scopes in various application areas. Generally, a Wireless Sensor Network contains hundreds or thousands of sensing nodes. It is desirable to make these nodes cheaper. This fact also instigates design of simple and yet efficient algorithms and protocols for data communication over the sensor network and also for the successful operation of the network. Though the sensor nodes are expected to be static throughout, the mobility of the sensor nodes gives rise to some more sophisticated applications like better environment monitoring and tracking. The mobility of the sensor nodes increases the complexity in the design of the algorithms and protocols since it increases the rate of topology change. In this paper, sensor node mobility is considered and a routing protocol for such a mobile sensor network has been proposed. The base station is considered to be powerful as well as static. The proposed routing protocol is hierarchical. The formation of clusters and cluster head node selection are done by the base station. During the clustering process, the sensor field is divided into some virtual grids. The sensor node mobility factor is considered during the cluster formation process. The communication between ordinary sensor nodes and the cluster head node is carried out in single hop fashion. And depending on the current topology, the communication between the cluster head node and the base station may be of multi-hop fashion. The performance of the proposed protocol in terms of energy efficiency is observed through simulation. The results of simulation are reported here. The future scope of the work is outlined.

Keywords- *Wireless Sensor Network; Mobility; Routing; Energy Efficiency; Clustering.*

I. INTRODUCTION

A Wireless sensor network (WSN) consists of a large number of battery-powered, resource-constrained wireless sensor nodes, which might be randomly deployed in close proximity to the phenomenon (*to be monitored*) for sensing and collecting the desired data from the surroundings [1][13]. The sensed data are routed from a sensor node back to the sink either through multi-hop or direct communication architecture. The sink may further communicate with a task manager node via the Internet or satellite network. Instead of sending the raw data to other nodes, the sensor nodes carry out local data processing called data fusion in order to remove redundancy in the sensory data. Thus the nodes transmit only the pre-processed data. The application scope of wireless sensor networks is very wide and varied.

They are used in commercial and industrial applications to monitor data that would be difficult or expensive to monitor

using wired sensors. Typical applications of wireless sensor network include habitat monitoring, object tracking, nuclear reactor controlling, fire detection, traffic monitoring, seismic detection, medical monitoring etc. [1][4][13].

The sensor nodes are mostly deployed in an ad-hoc fashion, without predetermined planning. The sensor nodes need to organize themselves into a form of multi-hop wireless communication network and forward collected data to the destination. Therefore, sensor network protocols and algorithms must have self-organizing capabilities. Moreover, the sensor nodes are energy constrained. And it is infeasible to renew the battery of the sensor nodes due to hostile environment of the deployed sensor nodes. Therefore, the protocols and algorithms designed for such networks need to be energy efficient too [2][13][14].

In this paper, we present an energy efficient communication protocol for a wireless sensor network with mobile sensor nodes. The work presented here is a cluster-based hierarchical communication protocol which can take care of mobile sensor nodes. In this protocol, the clustering of nodes and cluster head node selection are done at the sink. During the clustering process, the sensor field is divided into some virtual grids. The sensor node mobility factor is considered during the cluster formation process. The communication between ordinary sensor nodes and the cluster head node is of single-hop fashion. And depending on the current topology, the communication between the cluster head node and the sink node may be of multi-hop type.

The rest of the paper is organized as follows. In section II, some previous related works are briefly reviewed. The proposed protocol is discussed in section III. In the section IV the performance of the proposed protocol is reported. Section V concludes the paper along with some directions for future work.

II. RELATED WORK

Many routing protocols for wireless sensor networks have been proposed in literature. The details of some popular routing protocols proposed for wireless sensor networks can be found in [2][3][8][9][10][11][16]. Some basic routing protocols for wireless sensor networks are reviewed in this section.

Flooding: In flooding [1][4][5], each node which receives a packet, broadcasts it unless the maximum hop count of the packet is not reached or the node itself is the destination of the

packet. It doesn't require complex topology maintenance or route discovery algorithm. Fig. 1 shows the process of flooding. However, it has the following disadvantages:

- 1) Implosion: This is the situation when duplicate messages are sent to the same node.
- 2) Overlap: Under this situation, the same event may be sensed by more than one node. This happens due to the overlapping regions of coverage.
- 3) Resource blindness: Under this situation, many redundant transmissions may occur. Here, the network routing protocol does not consider the available energy at the nodes while data packets are being transmitted.

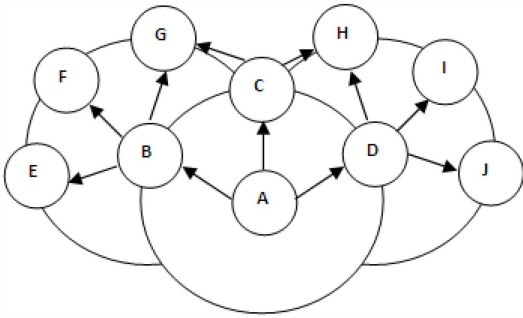


Fig.1. Flooding

Gossiping: It is a modified version of flooding where a node does not broadcast a packet but it sends the packet to a randomly selected neighbor [4][5]. Thus the protocol avoids the problem of implosion. It doesn't guarantee that all the nodes present in the network will receive the message. The major disadvantage of this protocol is that the message takes a long time to propagate throughout the network.

Sensor Protocols for Information via Negotiation (SPIN): SPIN [4][5] addresses the deficiencies of classic flooding by the method of negotiation and resource adaptation. SPIN uses three types of messages: ADV, REQ, and DATA. When a node has data to share, it first broadcasts an ADV message containing meta-data. A neighbor then responds with REQ message if it is interested in the advertised data. After receiving this message the sender node sends DATA. This cycle continues. Using this method of negotiation, it guarantees that only nodes that are interested in the data i.e., DATA, will receive it. Moreover, ADV and REQ messages contain only meta-data, therefore, they are cheaper in terms of energy requirements to send and receive. SPIN is a more sophisticated and energy aware scheme for data dissemination. This protocol reduces the amount of energy expended. It also solves the problems like implosion, overlap, and resource blindness which are issues in flooding [4]. This protocol also ensures that only interested nodes will expend their energy to receive data.

Sequential Assignment Routing (SAR): SAR [4][5] creates multiple trees where the root of the tree is one-hop neighbor from the sink. Each tree grows outwards from the sink. In this approach, the nodes with low throughput or high delay and low energy level are avoided. Under this protocol, it is possible that at the end of the tree formation process, a node may belong to multiple trees. This enables a node to choose a tree with shortest path to relay its data back to the sink.

Low Energy Adaptive Clustering Hierarchy (LEACH): LEACH [7] is a hierarchical communication protocol that divides the network into clusters. Each cluster contains an elected sensor node to act as cluster head. The cluster head node is the entity responsible for managing communication among member nodes of the cluster. Cluster head node also does data processing, and then it relays processed sensory data to the sink directly. It outperforms flat network protocols like direct communication with the sink, in terms of network lifetime. But LEACH is not suitable for large networks because of direct communication involved between cluster head node and the sink.

BeamStar: BeamStar [11] is an edge-based approach for routing in wireless sensor networks. In this protocol, the sensor nodes are relieved of the activities that are associated with control and routing. Moreover, under the influence of this protocol, the capabilities of the base station are exploited without sacrificing the network performance.

EBRP: In Energy Balanced Routing Protocol (EBRP) [18], the packets move towards the base station through dense energy area and thus protect the nodes with relatively low residual energy. This protocol uses the concept of potential in physics and constructs a mixed virtual potential field in terms of depth, energy density, and residual energy. EBRP prolongs the lifetime of the network but it does not consider the issue of reliable data delivery. This protocol also does not consider mobility of the sensor nodes and the base station.

All the above mentioned routing protocols consider static network in which the sensor nodes as well as the sink are static. These protocols cannot handle node mobility and therefore, the performance of these protocols may degrade in presence of node mobility.

III. PROPOSED PROTOCOL

In the proposed protocol, it is considered that the sensor nodes have moderate mobility and the sink is static. The terms sink and base station are used interchangeably. The base station is responsible for creation of clusters and selection of cluster head nodes. The size of the clusters may vary depending on the mobility of the sensor nodes. Initially, the sensor field is divided into grids of equal size. As per LEACH [7], the total number of cluster head node is five percent (5%) of the total number of sensor nodes deployed. Hence the number of grids will be greater than number of clusters. The grids are combined together to form clusters. A cluster head of a cluster is selected by the base station and all other sensor nodes of the cluster communicate with the cluster head. If the cluster head is far from the base station then it uses the multi-hop communication to transmit data.

System Model

The system model considered in this work can be described in terms radio model and mobility model. The radio model talks about the communication media and the characteristics of it in terms of energy requirements for signal transmission and reception. On the other hand the mobility model talks about the mobility characteristics of the sensor nodes.

Radio Model: We consider the same radio model as used in LEACH [7]. The energy loss proportional to d^2 , where d is the physical separation between the transmitter and receiver, is considered. Fig. 2 depicts the radio transmission model.

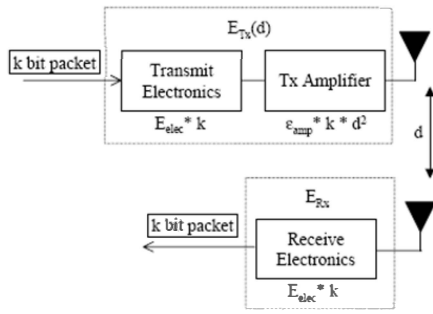


Fig. 2. K bit packet transmission model

As per the first order radio model [6][7], in order to transmit a k -bit message over a distance d , the energy expenditures are as mentioned below:

$$E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d) \quad (1)$$

$$E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2$$

Similarly, in order to receive this message radio expends energy governed by the following relation:

$$E_{Rx}(k) = E_{Rx-elec}(k) \quad (2)$$

$$E_{Rx}(k) = E_{elec} * k$$

Mobility Model: In the proposed protocol, the sensor nodes are mobile. The sensor nodes move in the sensor field as per the random waypoint mobility model [17]. Fig. 3 shows the movement of a node following random waypoint mobility model.

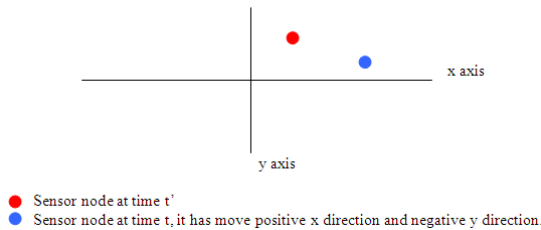


Fig. 3. Sensor nodes in 2-D plane

B. Phases of the Protocol

The proposed protocol consists of five phases. These five phases are discussed in this section. Fig. 4 shows these phases of the protocol.

- Phase 1: Formation of the virtual grids
- Phase 2: Formation of clusters from virtual grids
- Phase 3: Selection of the cluster head
- Phase 4: Data transmission
- Phase 5: Re-clustering

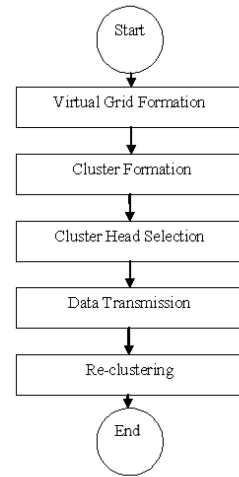


Fig. 4. Different phases of the protocol

Formation of the virtual grids: The sensor field is divided into equal sized virtual grids. The grids are of square shape and number of grids generated is based on the assumption that 5% of the total sensor nodes in the field can become cluster head. Let us consider that the number of sensor nodes be 100. Then only 5 sensor nodes can become cluster head. This means that the number of grids will be greater than 5. For example, let us consider a sensor field of size 1000x1000 sq meters. Then the field can be divided into some grids (*more than 5*) but each grid should be of equal size. For simplicity, let the number of grids be 4*4=16 as shown in Fig. 5. Each grid is made of equal size with an aim to have uniform distribution of sensor nodes inside each cluster and uniform geographic area coverage by each cluster. The number inside each grid in the Fig. 5 shows the number of sensor nodes inside each virtual grid in the field.

18	5	2	7
4	2	10	0
0	9	20	6
0	3	6	8

Fig. 5. Sensor nodes in different grids

As only 5 sensor nodes can become cluster head in a sensor network of 100 nodes, hence we fix a **threshold value** which should be equal to or greater than 100/5=20. This threshold value plays a role in forming the clusters which is discussed in the following section.

Formation of clusters from virtual grids: After the grids are generated, the next step is the formation of clusters. All the grids are checked to see if the number of sensor nodes inside each grid

is greater than the *threshold value*. If it is greater, then the grid itself is declared as one cluster else the neighboring grids are grouped together to form clusters based on the threshold value. This process continues until the entire grids are scanned and clusters are generated.

The algorithm is given below.

```

Input:      Grid information
Output:    Cluster information
for each grid i,
Step1:     Scan the grid
Step2:     If number of nodes in the grid is greater than threshold
           value then the grid is declared as a cluster itself and
           go to step 4 else go to step 3.
Step3:     Select its neighbor grids one at a time and check if
           after combining the number of nodes present in the
           neighboring grid with the number of nodes in itself
           exceeds the threshold value. The moment the total
           number of nodes after grouping the grids becomes
           equal to or greater than the threshold value, declare
           the grouped grids as one cluster.
Step4:     If all the grids are scanned and combined to form
           clusters than go to step 5 else scan the next grid and
           go to step 2
Step5:     Stop

```

Selection of the cluster head: After formation of the clusters, the next phase is the selection of the cluster head for each cluster. As the sensor nodes are mobile, there is a possibility that the sensor nodes may move away from the cluster. Such node cannot be a candidate for becoming a cluster head. If a sensor node does not move away from the cluster, then the parameters like *the available energy* and *the distance of it from the base station* are considered for selecting it as a cluster head. Ideally, a cluster head node should have energy more than a level, i.e., threshold level. Again an ideal cluster head node should not be located far away from the base station. Ideally, the distance between the cluster head node and the base station should be the minimum in comparison to the other sensor nodes inside the cluster. Essentially, the cluster head node needs to remain within the boundary of the cluster in spite of its mobility. Moreover, the cluster head node should always be a high energy node since it needs to do maximum amount of processing tasks and also communication tasks. The algorithm is stated below.

Note 1: It is assumed that the sensor node can find its geographic location by using some GPS free solutions as discussed in [12][15].

Data transmission: TDMA based scheme is used for transmission of data [6][7]. Cluster head aggregates the data and send it to the base station after a regular interval of time. Cluster head uses multi-hop transmission if the base station is far away.

Re-clustering: At the end of each round, clusters and cluster-heads are re-computed on the basis of current position of the sensor nodes. This is done by the base station. There is a possibility of change in the number of clusters after each round and this is due to the mobility of the sensor nodes.

```

Input:      max_energy, min_distance
Output:    cluster head
Begin
max_energy = 0, min_distance = ∞
foreach cluster do
ID=0;
  Begin
for each sensor node in the cluster do
  Begin
find the position of the sensor node1
if the position does not fall outside the cluster
then
if sensor node energy > max_energy then
if base station distance from the node
< min_distance
  Begin
max_energy = sensor node energy
min_distance = distance between the
sensor node and the base station
ID = sensor node identification number
  End
  End
Sensor node with ID becomes the
cluster head of the cluster.
  End
End
End

```

IV. RESULTS AND DISCUSSION

For simulation of the proposed protocol, we considered an area of $1000 \times 1000 \text{ m}^2$ for the network deployment. We considered the following parameters given in Table I.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of nodes	10
Data packet size	250 Bytes
Packet rate	60 packets/session
Number of sessions	24 session
Duration of each session	60 sec
Initial energy	10 Joules
Speed of nodes	0-3 m/sec

Based on these parameters, we have studied the energy consumption in sensor nodes with respect to different mobility levels of the nodes. Simulation of 10 nodes for 24 sessions was carried out. Each session is of 60 seconds. An analysis regarding the energy consumption of different nodes that incurred during the simulation is shown through various graphs (Fig. 6 to Fig. 9) below.

Fig. 6 demonstrates the residual energy that is available in different nodes at different point of time during simulation while the nodes are static. The residual energy level reduces along with time due to energy expenditure that occurs against packet transmission and packet reception. Energy expenditure at node 1 is the maximum because it acted as the cluster head. Again there was no energy expenditure at node 6 since this node did not take part in data forwarding. In this analysis, we consider the energy expenditure that occurred due to transmission and reception of packets only.

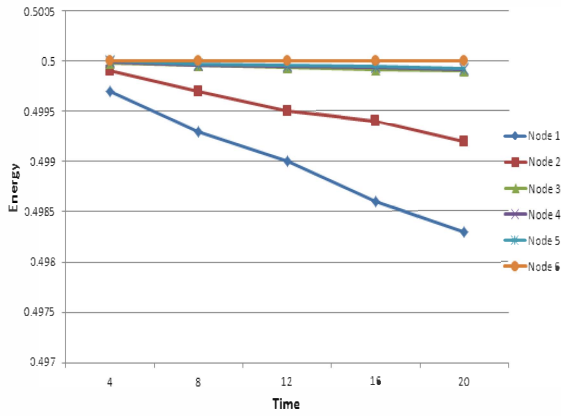


Fig. 6. Residual energy level when nodes are static (Energy in *Joule* and Time in *Minute*)

Fig. 7 shows residual energy level at different nodes at different point of time while the nodes move with a speed of 1 m/s. The node 2 has the maximum energy expenditure due to the fact that it acted as the cluster head.

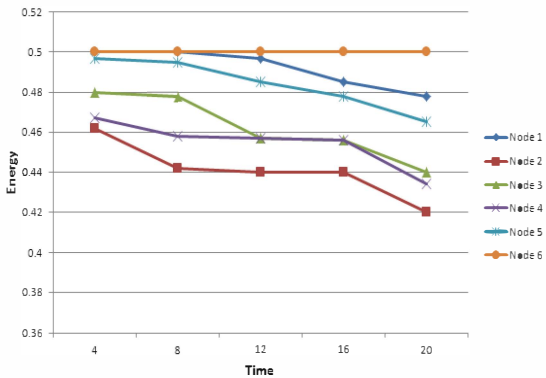


Fig. 7. Residual energy when nodes move with a speed of 1m/s (Energy in *Joule* and Time in *Minute*)

Fig. 8 shows the residual energy level of different nodes at different point of time while the nodes move with a speed of 2 m/s. Similarly, Fig. 9 shows the residual energy level of different nodes while the nodes move with a speed of 3 m/s.

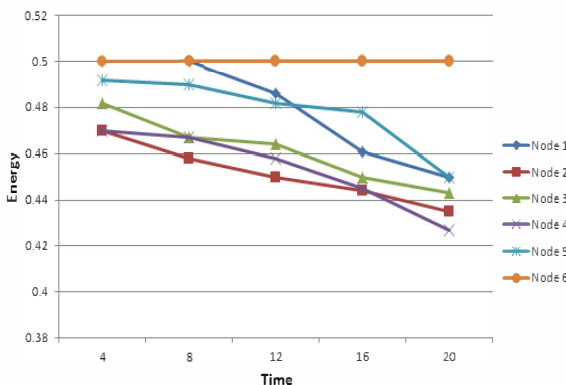


Fig. 8. Residual energy when nodes move with a speed of 2m/s (Energy in *Joule* and Time in *Minute*)

It is obvious that some nodes expend more energy than others considering all scenarios. This is so, because those nodes which expend more energy are the nodes involved in higher volume of data packet transmission and reception. Cluster heads are examples of such type of nodes.

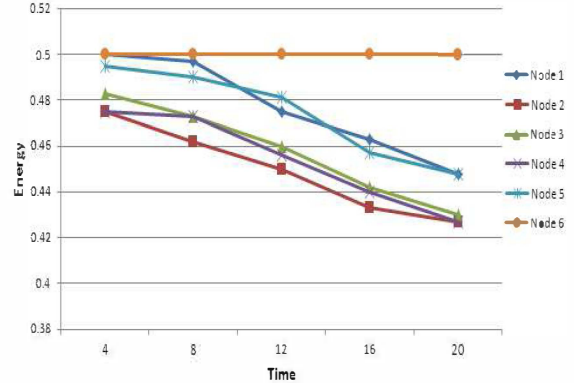


Fig. 9. Residual energy when nodes move with a speed of 3m/s (Energy in *Joule* and Time in *Minute*)

V. CONCLUSION AND FUTURE SCOPE

A novel routing protocol for wireless sensor network is proposed. The protocol considers node mobility. The proposed protocol is a cluster based hierarchical one. The simulation results show energy expenditure analysis in the network during the operation of the network. The protocol can further be extended to handle sink mobility as well. Moreover, the number of clusters formed is fixed and it is 5% of the total number of nodes deployed. As another future scope of this work, effort can be made to determine the number of clusters dynamically depending on the mobility of the nodes.

Such a provision will help in providing a scalable solution for the routing problem in large wireless sensor networks. The performance of the proposed protocol can further be analyzed through mathematical modeling and more rigorous simulation experiments.

REFERENCES

- [1] Feng Zhao, Leonidas Guibas, *Wireless Sensor Networks an information processing approach*, Morgan Kaufmann Publishers, An imprint of Elsevier, 2005, ISBN 81-8147-642-5.
- [2] S. Singh, M. Woo, C. Raghavendra, "Power-Aware Routing in Mobile Ad Hoc Networks", in *Proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom '98)*, Oct. 1998.
- [3] V. Rodoplu, T.H.Meng, "Minimum Energy Mobile Wireless Networks", *IEEE Journal Selected Areas in Communications*, vol. 17, no. 8, Aug 1999, pp. 1333-44.
- [4] J. N. Al-Karaki, A. E. Kamal, "Routing Techniques in Wireless Sensor Networks: A Survey", *IEEE Wireless Communications*, vol. 11, no.6, Dec. 2004, pp. 6-28.
- [5] K. Akkaya, M. Younis, "A survey on routing protocols for wireless sensor networks", *Elsevier Ad Hoc Networks Journal*, vol. 3, no. 3, 2005, pp. 325-349.

- [6] W.B.Heinzelman, A.P.Chandrakasan, H.Balakrishnan, "An application-specific protocol architecture for wireless micro sensor networks", *IEEE Transactions on Wireless Communications*, vol.1, no.4, 2002, pp. 660-670.
- [7] Wendi RabinerHeinzelman, AnanthaChandrakasan, HariBalakrishnan. "Energy Efficient Communication Protocol for Wireless Microsensor Networks", in *Proceedings of the Hawaii International Conference on System Sciences*, January 4-7, 2000, Hawaii.
- [8] A. Manjeshwar, D.P. Agarwal, "TEEN: a Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks", in *Proceedings of 1st Int'l Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing*, San Francisco, USA, April 2001, pp. 2009-2015.
- [9] A. Manjeshwar, D.P. Agarwal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks", in *Proceedings of Int'l. Parallel and Distributed Processing Symposium (IPDPS)*, Fort Lauderdale, USA, 2002, pp. 195-202.
- [10] S. Lindsey and C.S. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information Systems", in *Proceedings of IEEE ICC 2001*, vol. 3, Jun 2001, pp. 1125-1130.
- [11] Shiwen Mao, Y Thomas Hou, "BeamStar: An Edge-Based Approach to Routing in Wireless Sensor Networks", *IEEE Transactions on Mobile Computing*, vol. 6, no. 11, November 2007, pp. 1284-1296.
- [12] HuseyinAkcan, VassilKriakov, Hervey Bronnimann, Alex Delis, "GPS-Free node localization in mobile wireless sensor networks", in *Proceedings of the 5th ACM international workshop on Data Engineering for Wireless and Mobile Access*, Chicago, Illinois, USA, June 25, 2006, pp. 35-42, ISBN 1-59593-436-7.
- [13] I. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks", *IEEE Communications Magazine* vol. 40, no.8, 2002, pp. 102-114.
- [14] F Ingelrest, David S Ryl, Ivan Stojmenovic, "Optimal Transmission Radius for Energy Efficient Broadcasting Protocols in Ad Hoc and Sensor Networks", *IEEE Transactions on Parallel and Distributed Systems*, vol. 17, no. 6, June 2006, pp. 536-547.
- [15] Mari Carmen Domingo, Rui Prior, "Design and Analysis of a GPS-free Routing Protocol for Underwater Wireless Sensor Networks in Deep Water", in *Proceedings of SENSORCOMM 2007*, Valencia, Spain, October 14-20, 2007, pp. 215-220,
- [16] Younis O, Fahmy S, "HEED: A Hybrid, Energy- Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks", *IEEE Transactions on Mobile Computing*, vol. 3, 2004, pp. 366-379.
- [17] Tracy Camp, Jelf Boleng, Vanessa Davies, "A Survey of Mobility Models for Ad Hoc Network Research". *Wireless Communications and Mobile Computing (WCMC): Special Issue on Mobile Ad Hoc Networking: Research, Trends and Applications*, vol. 2, no.5, 2002, pp. 483-502.
- [18] FengyuanRen, Jiao Zhang, Tao He, Chuang Lin, Sajal K. Das, "EBRP: Energy-Balanced Routing Protocol for Data Gathering in Wireless Sensor Networks", *IEEE Transaction on Parallel and Distributed Systems*, vol. 22, no. 12, Dec. 2011, pp. 2108-2125