Mobility-based Greedy Forwarding Mechanism for Wireless Sensor Networks

Riad Kouah, Mohamed Aissani
Research Unit in Computer Science
Ecole Militaire Polytechnique (EMP)
P.O. Box 17 Bordj-El-Bahri, Algiers, Algeria
riadkouah@hotmail.com, maissani@gmail.com

Samira Moussaoui
Computer Science Department
University of Science and Technology (USTHB)
P.O. Box 32, Bab-Ezzouar, Algiers, Algeria
smoussaoui@usthb.dz

***Abstract*—Geographic routing in mobile sensor networks has attracted attention in recent years. When a sensor node has a packet to forward, it selects the closest available neighbor to the sink as next forwarder regarding only location parameter. However, this strategy does not consider the mobility of sensor nodes. To overcome this problem, we propose in this paper an efficient geographic routing mechanism based on a new next-hop selection metric. It combines the distance to the sink, the moving direction and the moving speed of the forwarding candidate neighbors. This moving direction is based on neighbor evolution in distance according to the sink calculated by a sender node between two successive received location beacons. Associated with the well-known GPSR routing protocol, our mechanism achieved good performance in both delivering data packets and conserving resources of sensor nodes.**

Keywords—mobile sensor networks; geographic routing; sensor mobility; greedy forwarding.

I. INTRODUCTION

Geographic routing in wireless sensor networks (WSNs), and especially greedy forwarding, is a new challenge when nodes move. In fact, the efficient and scalable greedy forwarding is a promising scheme for large-scale WSNs when location of each node is available [1, 2]. Indeed, the current packet is forwarded to a 1-hop neighbor who is closer to the sink than the sender node. This process is repeated until the data packet reaches the sink. Traditionally, the next-forwarder selection is based only on the location parameter. However, this can degrade the performance of geographic routing in mobile WSNs. The location failure, which is resulted from mobility of nodes, degrades the routing performance in delivering packets and wastes the limited energy of nodes.

Although existing works [3-9], summarized in Section II, play important roles in improving the performance of the geographic routing in mobile WSNs, design of new routing solutions is still a challenging research area. Thus, we first analyze in this paper the impact of node mobility on the routing performance and then we propose an efficient geographical routing mechanism, called MGF (Mobility-based Greedy Forwarding), which combines the distance to the sink, the moving direction and the moving speed of the forwarding candidate neighbors of a sender node in a new routing decision metric. This combination is also used the DGF (Direction-based Greedy Forwarding) mechanism that we have proposed in our previous work [10]. The difference between the two mechanisms is explained as follows. To calculate a neighbor moving direction according to the sink, the DGF mechanism uses the neighbor evolution in both distance and angle between two successive location beacons that receives a sender node, but the MGF mechanism uses the neighbor evolution in distance only.

We associate the proposed MGF mechanism with the well-known GPSR (Greedy Perimeter Stateless Routing) protocol [2] in order to improve its efficiency in mobile WSNs and the obtained protocol is called GPSR-MS (GPSR with Mobile Sensors). The major difference between GPSR-MS and existing protocols dedicated for mobile WSNs (Section II) includes the following aspects:

- GPSR-MS operates without organizing network in clusters, while the majority of existing routing protocols designed for mobile WSNs are cluster-based where the maintenance process consumes many resources of sensor nodes.
- In existing cluster-based routing protocols, the greedy forwarding mode is not applied, while the GPSR-MS protocol is based on this scalable and efficient mode.
- Few of existing routing protocols are designed for mobile WSNs. Therefore, the GPSR-MS protocol strengthens this class of protocols. Our objective is to maximize the packet delivery ratio with the minimum consumption of energy.

The rest of the paper is organized as follows. Section II presents the main routing schemes and protocols proposed in literature for mobile WSNs. Section III discusses the node mobility effect on the greedy forwarding performance. Section IV presents the proposed MGF mechanism. Section V evaluates performance of our proposal. Section VI concludes the paper.

II. RELATED WORKS

Node mobility has added several challenges in mobile WSNs. One of these challenges is routing. Existing routing protocols in mobile WSNs based on type of nodes are regrouped in three classes: protocols that support static nodes and mobile sink(s) [3-4], protocols that support mobile nodes and static sink(s) [5-8], and protocols that support mobile nodes and mobile sink(s) [9]. In literature, the majority of works have been focused on the first class of protocols. In other hand, there are less works concerning both the second and the third class.

Fodor et al. [3] propose the gradient-based routing protocol (GBRP) to use mobile sinks that move in order to decrease the energy consumption of the whole network. In GBRP, sensor nodes maintain a list of neighboring next hops that are in the right direction towards the closest sink. The protocol uses a restricted flooding to update locations of the mobile sinks. The principle behind is to register by each node the cost between the appropriate sink and the given node and to update only these routing entities where the relative change in cost is above a threshold. Wang et al. [4] propose a mobile sink routing protocol (MSRP) with registering in cluster-based mobile WSNs. The MSRP architecture consists of four phases: clustering, registering, dissemination and maintenance. The cluster-heads are elected and the network is divided into multiple clusters during the first phase. The mobile sink which comes into the communication range of a cluster-head is registered into this cluster using the second phase. Once the mobile sink is registered, it immediately receives from the cluster-head all sensed data in the cluster during the third phase. Possible new sensor nodes are added to the cluster and the cluster-head is then evaluated during the fourth phase. Yang et al. [5] propose a dynamic enclose cell (DEC) routing algorithm which decreases the control overhead by constructing cells to retain stable the network in high mobility. DEC groups the nodes into cells and develops the routing path using the cells boundaries. When the nodes are moving, only the adjacent cells of the moving nodes are reconstructed. In this way, the negative impact of the node mobility is minimized. Arboleda et al. [6] propose a cluster-based routing (CBR) protocol for mobile WSNs using zone-base information and a cluster-like communication between nodes. The CBR protocol is based on two stages: route creation and route preservation. Lambrou et al. [7] present a routing scheme for hybrid mobile WSNs that forwards packets to mobile nodes. The routing of data messages, containing position of each detected event, can be easily achieved using a geographic routing based on greedy techniques towards a fixed sink. Moreover, the sink can easily request information from a specific region or even a single static node using the position information. Santhosh-Kumar et al. [8] propose an adaptive cluster-based routing (ACBR) scheme for mobile WSNs by including mobility as a new criterion for creation and maintenance of clusters. Saad et al. [9] propose an energy efficient routing algorithm called Ellipse-Routing. Using a region-based routing, the proposed algorithm builds a virtual ellipse thanks to the source and the sink geographic positions. So, only nodes within this ellipse can forward a message towards the sink. Then, the algorithm was extended in order to take in account the errors that occur in node location.

III. NODE MOBILITY EFFECT ON GREEDY FORWARDING

In greedy forwarding, the selected next forwarder is the closest neighbor to the sink in term of distance, projection, or direction based only on the nodes' location. But, mobility of nodes causes the problem of location information freshness inside the neighbors table of each sender node. This may result failures in routing decisions. This problem can be resolved by broadcasting location beacons. But when node mobility increases rapidly, the beaconing overhead (packet control) grows also rapidly.

When nodes move, the greedy forwarding mode does not often guaranty positive progression of data packets towards the sink. Thus, when a sender node selects its next forwarder, the later may be not available because it moved. In the other hand, another node can comes into the sender neighborhood, but it is not considered when selecting the next forwarder because it was not detected by the sender node. This situation has its importance when the non-detected node is the closest neighbor to the sink.

Figure 1 shows the impact of location beaconing period on greedy forwarding. When this period is long, table of neighbors of current node i will be obsolete due to movements of nodes y and z. At time t_0 (Figure 1-a), node y is leaving the communication range of node i and node z is coming into this range. At time t_1 (Figure 1-b), if node i selects as forwarder node y (i.e., a non-available neighbor), the packet will be lost due to link failure. In the other hand, the non-detected neighbor z is not considered by node i although it is the closest neighbor to sink s.

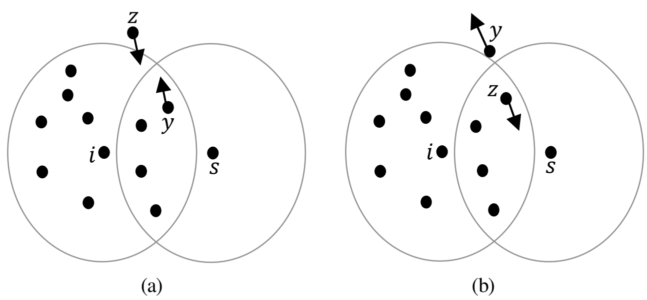

Figure 1. Beaconing period impact on greedy forwarding.

Figure 2 presents the nodes' moving direction impact on the greedy forwarding. At time t_0 (Figure 2-a), node z moves toward sink s and node y moves in the opposite sense of sink s. However, at time t_1 (Figure 2-b), node z will be the closest neighbor to sink s according to node y. But, the closest neighbor in the neighbors table of node i is always node y. Because the obsolete table of node i, the packets that should be sent to node z will be always sent to node y. This problem will be resolved in next broadcasting period. Figure 3 depicts the nodes' moving speed impact on the greedy forwarding. Current node i has two neighbors: node y and node z that move in the same direction regarding sink s, but node z is more speedy than node y. At time t_0 (Figure 3-a), node y is closest to sink s than node z. Then node y is the best forwarder node. At time t_1 (Figure 3-b), node z becomes closer to sink s than node y. But, node z will not be considered as the new best forwarder because the neighbors table of current node i is not yet updated.

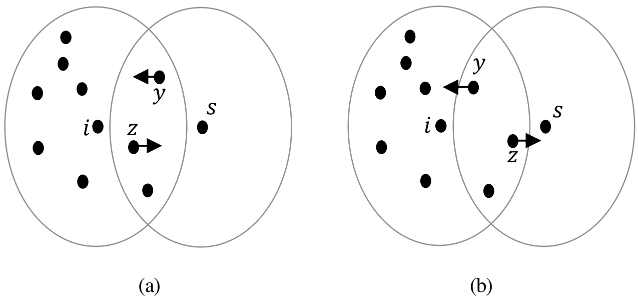

Figure 2. Node moving direction impact on greedy forwarding.

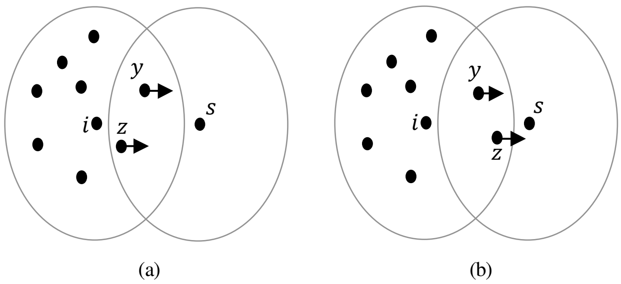

Figure 3. Nodes' moving speed impact on greedy forwarding.

Also, mobile nodes can repair voids that appear in a WSN due to their moving propriety. Consequently, greedy forwarding mode will be more preferment by using the shortest paths. With mobility of nodes, effect of the problem caused by voids (holes) on geographic routing performance is reduced [11]. In fact, the movement of sensor nodes can eliminate some voids created in WSNs. Thus, a geographic routing protocol, such as GPSR, reduces the use of bypassing mode where routing paths are long and then the energy consumption is excessive and the end-to-end delay is extended.

In greedy forwarding mode, the progress of packets toward the sink is rapid. Figure 4 shows the positive impact of nodes' mobility on routing-path length, between source node s and destination node z, by repairing a void without using a specific scheme. Consequently, GPSR will use reedy mode in the most cases. At time t_0 (Figure 4-a), a void appears in network. At time t_1 (Figure 4-b), this void is repaired thanks to movement of some nodes. Then, average path length, end-to-end delay and energy consumption will be reduced significantly.

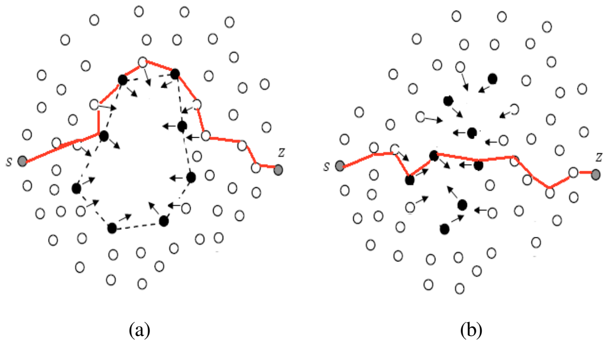

Figure 4. Nodes' movement impact on repairing voids.

IV. PROPOSED MGF MECHANISM

To be efficient in mobile WSNs, the proposed MGF mechanism uses a new decision metric when selecting the next forwarder of the current packet. This metric considers the moving direction, the moving speed, and the distance to the sink of forwarding candidate neighbors of the sender node. The MGF mechanism supposes that each node moves with a strict direction according to the sink. However, each neighbor of a node i can moves toward sink s, moves away from sink s, or stills static according to sink s. The moving direction is defined by the distance variation of the neighbors according to sink s, as shown in Figure 5. The moving direction of neighbor n, between two recent times t_0 and t_1, is calculated using its two last distances to sink s. Neighbor n may approaches (or far from) sink s in term of distance variation.

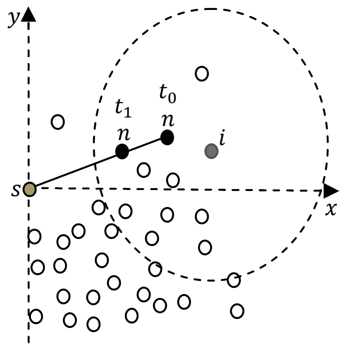

Figure 5. Node approaching to the sink in term of distance.

The greedy mode weaknesses, discussed in this section, induce packet losses, delivery delays and excessive energy consumption. Indeed, the use of only distance to select the intermediate forwarders has limits in dynamic environments caused by nodes' mobility. However, the use of periodic and frequent location beacons cannot resolve the problem because it creates packet collisions, overloads the network and consumes more energy. Consequently, some packets will be lost and other packets will be delayed. Therefore, the next forwarder selection in a node must consider multiple

 ISBN: 978-1-61208-256-1

metrics of its neighbors, such as moving speed, moving direction and distance to the sink. The objective is to obtain a geographic routing protocol that maximizes the packet delivery ratio, minimizes the average path length and reduces the control packet overhead.

We suppose a WSN formed by one static sink and several mobile nodes. Thanks to network initialization phase, each node knows its position, positions of its neighbors, and the sink's position. Also, each node has a table (TABLE I) which contains information about its neighbors, such as location, moving speed and moving direction. The proposed MGF mechanism operates in two following phases: neighbors' information update and next-forwarder selection.

1) Neighbors' information update: Each sensor node broadcasts periodically a 1-hop location beacon informing its neighbors about its geographic position. The period of this beacon can be fixed according to the nodes' moving speed. Thanks to these beacons, each node updates a local table containing information about all neighbors. We added to these table two new fields to record moving speed and moving direction of each neighbor. TABLE I shows the structure of the neighbors' table of a node. We also added a specific field in a location beacon, where the structure is given in TABLE II, to convey the moving speed of a node to all its neighbors. When a node i receives a beacon B from its neighbor n, it checks the existence of n in its neighbors' table T. If node n does not exist, node i inserts information concerning n in T (TABLE I), else it calculates the new moving direction of n by using Formula (1), where $DT(n,s)$ represents the old distance separating $x_{n,T}$ from sink s calculated using T, $DB(n,s)$ is the new distance separating n from s calculated using B. The distances $DT(n,s)$ and $DB(n,s)$ are based on locations that are extracted from T, respectively from B, are given by the respective formulas (2) and (3). Note that $x_{n,T}$ and $y_{n,T}$ are locations of n in T, $x_{n,B}$ and $y_{n,B}$ are locations of n in B, x_s and y_s are locations of sink s in current node i. Once the above calculations are done by node i, it updates all information concerning each neighbor n in its table T.

$$Dir(n,s) = \frac{DT(n,s)}{DB(n,s)} \tag{1}$$

$$DT(n,s) = \sqrt{(x_{n,T} - x_s)^2 + (y_{n,T} - y_s)^2} \tag{2}$$

$$DB(n,s) = \sqrt{(x_{n,B} - x_s)^2 + (y_{n,B} - y_s)^2} \tag{3}$$

2) Next-forwarder selection: This phase aims to enhance the greedy mode of GPSR by handling parameters of the mobile nodes. Thus, we propose a new routing factor combining three parameters: 1) distance $DT(n,s)$ between neighbor n and sink s, 2) moving direction $Dir(n,s)$ of neighbor n and 3) moving speed $Speed(n)$ of neighbor n. When current node i has to send a packet to sink s, by using a greedy forwarding, it selects from its neighbors table a node n having the smallest $MGFactor(n,s)$ given by Formula (4), where direction $Dir(n,s)$ is given by Formula (1). Note that when $Dir(n,s)$ is equal to 1 then n is static, when it is greater than 1 then n approaches the sink, and when it is less than 1 then n moves away from the sink.

$$MGFactor(n,s) = \frac{DT(n,s) * Dir(n,s)}{Speed(n)} \tag{4}$$

TABLE I. STRUCTURE OF A NEIGHBORS TABLE.

Field	Mission/Content
ID	Identifier of a neighbor node
Position	Coordinates (x_j, y_j) of a neighbor j
Direction	Neighbor moving direction
Speed	Neighbor moving speed
ExpTime	Expire time of a neighbor in the table

TABLE II. STRUCTURE OF A LOCATION BEACON.

Field	Mission/Content
ID	Identifier of the node that sent a beacon
Position	Location of the node that sent a beacon
Speed	Moving speed of the node that sent a beacon

V. PERFORMANCE EVALUATION

We first implemented and evaluated the traditional GPSR protocol using the simulator NS2 [12] with mobility of nodes. Then we associated the proposed MGF mechanism with GPSR and evaluated in same conditions the resulting protocol (GPSR-MS). Since GPSR can handle mobility of nodes by reducing the location beacon period, we evaluate performance of this protocol under four values of this period (2, 3, 4 and 5 milliseconds) and obtained results are shown in the graphs as GPSR(2), GPSR(3), GPSR(4) and GPSR(5), respectively. This period is set to 5 milliseconds (ms) for the proposed GPSR-MS protocol.

For our simulations, we used a terrain 600×600 meters with 350 mobile sensors deployed randomly. Then they moves according to Random Waypoint Model (RWM) with a random speed in [5-20] mps (meter per second) to simulate the mobility in realistic environments. The sink is placed at the center of the terrain and 12 sources are selected randomly. Each source generates one CBR flow with a rate increased step by step from 1 to 12 pps (packet per second). For each rate and at the end of the simulation time, we measure the packet delivery ratio, the control packet overhead, the average path length and the network energy consumption per delivered packet.

Compared to the original GPSR protocol in Figure 6, the proposed GPSR-MS protocol achieves a better packet delivery ratio. Indeed, the number of packets dropped in

GPSR is important when a beaconing period is large (5 milliseconds). Also, Figure 7 shows a good performance of GPSR-MS in term of average path length compared to the original GPSR protocol. This is due to our MGF mechanism that dynamically selects as next forwarders the neighbors that move toward the sink.

Note that when the location beacon is not large (2 milliseconds) the average routing-path length is reduced in the original GPSR protocol because tables of neighbors of sensor nodes are frequently updated. Consequently, GPSR generates many location beacons that overload the network (Figure 8) and then consumes excessive energy of sensor nodes (Figure 9). On the other hand, the proposed GPSR-MS protocol delivers more data packets, generates less control overhead and optimally manages energy of nodes compared to all variants of the GPSR protocol.

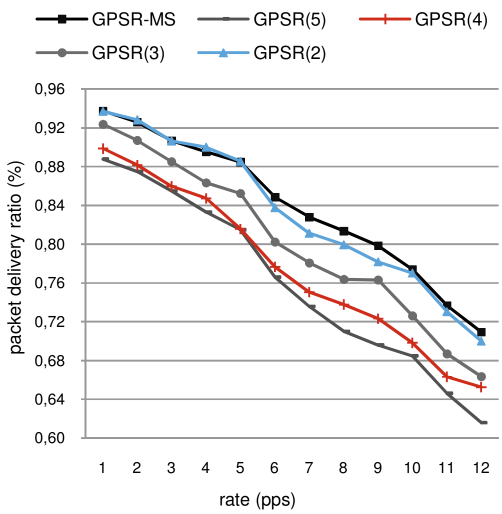

Figure 6. Packet delivery ratio *vs.* source rate.

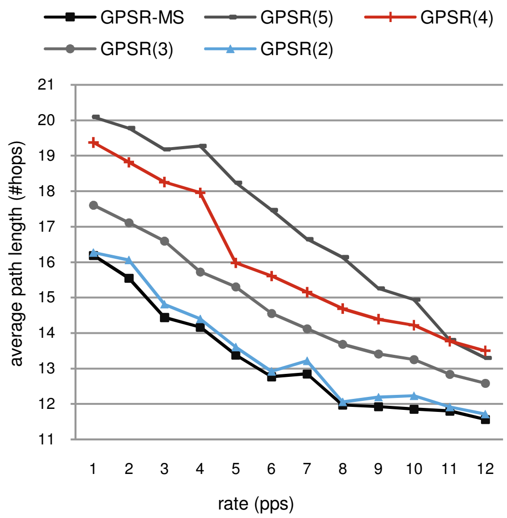

Figure 7. Average path length *vs.* source rate.

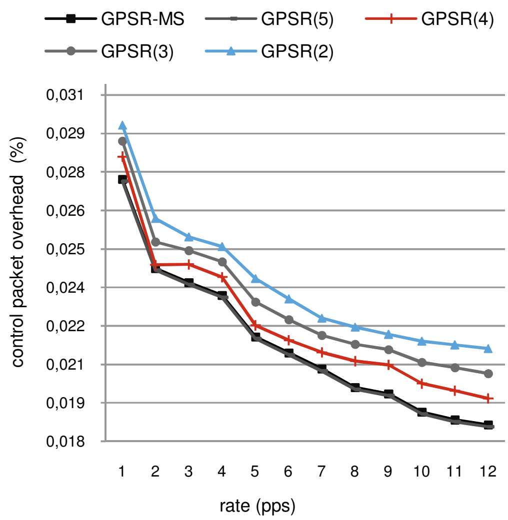

Figure 8. Control packet ovearhead *vs.* source rate.

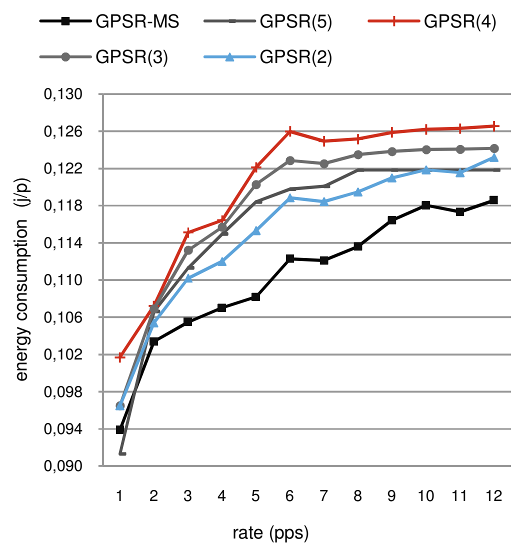

Figure 9. Energy consumption *vs.* source rate.

VI. Conclusion

Existing geographic schemes using greedy forwarding in mobile WSNs still have problems according mobility of sensor nodes. To contribute on solving these problems, we have proposed the MGF mechanism for mobile WSNs. It is simple to implement, saves the network resources and could be associated with various geographic routing protocols. The merit of our proposal is that the current packet is forwarded to the best neighbor node in terms of distance, moving direction and moving speed according to the static sink. We have associated the MGF mechanism with the well-known GPSR protocol and the resulting protocol, called GPSR-MS, has achieved good performance compared to different versions of the original GPSR. Indeed, GPSR-MS delivers more packets, broadcasts less control packets, uses the shortest routing paths and economizes much energy of sensor nodes. Our future work will evaluate performance of the GPSR-MS protocol with the group mobility concept.

REFERENCES

[1] Q. Fang, J. Gao, and L.J. Guibas, "Locating and bypassing holes in sensor networks," IEEE Mobile Networks and Applications, vol. 11(2), pp. 187–200, April 2006.

[2] B. Karp and H. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," Proc. of the ACM/IEEE Conference on Mobile Computing and Networking, pp. 243-254, Boston, Massachusetts, USA, August 6-11, 2000.

[3] K. Fodor and A. Vidacs, "Efficient Routing to Mobile Sinks in Wireless Sensor Networks," Proc. of the 2nd International Workshop on Performance Control in WSNs (PWSN), pp. 1–7, Austin, Texas, USA, October 23, 2007.

[4] Y.H. Wang, K.F. Huang, P.F. Fu, and J.X. Wang, "Mobile Sink Routing Protocol with Registering in Cluster-Based WSNs," Proc. of the 5th International Conference on Ubiquitous Intelligence and Computing, pp. 527-535, Oslo, Norway, June 23-25, 2008.

[5] Y. Yang, L. Dong-Hyun, P.K. Myong-Soon, and I.H. Peter, "Dynamic Enclose Cell Routing in Mobile Sensor Networks," Proc. of the Asia-Pacific Software Engineering Conference (APSEC), pp.736-737, Busan, Korea, Nov. 30 – Dec. 3, 2004.

[6] M. Liliana, C. Arboleda, and N. Nidal, "Cluster-based Routing Protocol for Mobile Sensor Networks," Proc. of the 3rd International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, pp. 24-28, Canada, August 7–9, 2006.

[7] C.G. Panayiotou, T. Theofanis, and P. Lambrou, "A Survey on Routing Techniques supporting Mobility in Sensor Networks," Proc. of the 5th International Conference on Mobile Ad-hoc and Sensor Networks, pp. 78–85, China, Dec. 14-16, 2009.

[8] G.S. Kumar, A. Sitara, and K.P. Jacob, "An adaptive cluster based routing scheme for mobile wireless sensor networks," Proc. of the 2nd International Conference on Computing, Communications and Networking Technologies, pp. 1-5, Karur, India, July 29-31, 2010.

[9] C. Saad, A. Benslimane, J. Champ, and J.C. Konig, "Ellipse routing: A Geographic Routing Protocol for Mobile Sensor Networks with uncertain positions," Proc. of the 2nd Int'l Conference on Future Generation Communication and Networking, pp. 1–5, Sanya, China, December 13-15, 2008.

[10] R. Kouah, S. Moussaoui and M. Aissani, "Direction-based Greedy Forwarding in Mobile Wireless Sensor Networks", Proc. of the Eighth Advanced International Conference on Telecommunications (AICT), Stuttgart, Germany, May 27-June 1, 2012.

[11] M. Aissani, A. Mellouk, N. Badache, and M. Boumaza, "A Novel Approach for Void Avoidance in Wireless Sensor Networks, International Journal of Communication Systems (IJCS), vol. 23(8), pp. 945–962, 2010.

[12] Collaboration between researchers at UC Berkeley, LBL, USC/ISI, and Xerox PARC. The ns Manual, on line at: *http://www.isi.edu/nsnam/ns/*, last access in Jan. 2013.

 ISBN: 978-1-61208-256-1