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Mobile Wireless Sensor Networks Overview

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Abstract— Mobile wireless sensor networks (MWSNs) have recently launched a growing popular class of WSN in which mobility plays a key role in the execution of the application. In recent years, mobility has become an important area of research for the WSN community. The increasing capabilities and the decreasing costs of mobile sensors make mobile sensor networks possible and practical. Although WSN deployments were never envisioned to be fully static, mobility was initially regarded as having several challenges that needed to be overcome, including connectivity, coverage, and energy consumption, among others.However, recent studies have been showing mobility in a more favorable light. In this article, an overview of proposals that evaluate mobile communication in WSNs is presented.

Index Terms— Mobile wireless sensor networks, Mobility, Overview.

1 Introduction

During the last decades, there has been a rapidly growing interest in communication technologies of wireless sensor networks (WSNs). Such a network is composed of one or multiple remote sinks and many tiny, low-power sensor nodes, each equipped with some actuators, sensing devices, and a wireless transceiver [1]. These nodes are massively deployed in a region of interest to collect information from their surroundings, and continuously report back to the remote sinks. Thus, WSNs can provide a convenient way to monitor physical environments. In recent years, a large amount of WSN-related applications such as object tracking, health monitoring, security surveillance, and intelligent transportation have been proposed.

A WSN is usually deployed with static sensor nodes to perform monitoring missions in the region of interest. However, due to the dynamic changes of events and hostile environment, a pure static WSN could face the following severe problems:

I. The initial deployment of a WSN may not guarantee complete coverage of the sensing field and connectivity of the whole network. Usually, sensor nodes may be scattered in a hostile region from the aircraft or by robots [2]. However, these randomly deployed sensors could not guarantee to cover the whole area and may be partitioned into several non-connected subnetworks, even though we scatter a huge amount of nodes. Moreover, the dynamic change of regions of interest and the existence of obstacles could make the problem become more difficult.

II. Sensor nodes are usually battery-powered and prone to errors. As some nodes die due to the exhaustion of their energy, there could exist holes in the WSN's coverage. In addition, these dead nodes may break the network connectivity. However, in many scenarios, it is quite difficult to recharge sensor nodes or deploy new nodes to replace these death nodes.

III. The WSN may be required to support multiple missions under various conditions [3]. For example, in an object tracking application, sufficient sensor nodes should be deployed along the track of the target, while in a boundary detection mission; there should be adequate nodes along the pre-described perimeter. These different requirements cannot be easily satisfied by deploying a large amount of sensor nodes, since provisioning for all possible combinations of mission requirements could not be economically feasible.

IV. Some applications may need sophisticated (and thus expensive) sensors to involve in. For example, one can image that in a military application, pressure sensors may be deployed along the boundary to detect whether any enemy intrudes in. However, these sensors can only report something passing but cannot describe what passes through them. In this case, more sophisticated sensing devices like cameras should be required to obtain more information. Nevertheless, it is infeasible to equip camera on each node because of their large number.

By introducing mobility to some or all the nodes in a WSN, we can enhance its capability and flexibility to support multiple missions and to handle the aforementioned problems. Although a WSN is usually considered as an ad hoc network in which nodes are extended with sensing capability, a mobile WSN and a mobile ad hoc network (MANET) are essentially different. Mobility in a MANET is often arbitrary, whereas mobility in a mobile WSN should be "intentional". In other words, we can

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control the movement of mobile sensors to conduct different missions.

2 MWSN Architectures

2.1 Network Structures

Mobile sensor networks can be classified into one, two, or three layer network architectures [4].

One Layer. Flat or planar, network architecture comprises a set of heterogeneous devices that communicate in an ad hoc manner. The devices can be mobile or stationary, but all communicate over the same network. Basic navigation systems such as [5] have a flat architecture.

Two Layer. This architecture consists of a set of stationary nodes, and a set of mobile nodes. The mobile nodes form an overlay network or act as data mules to help move data through the network. The overlay network can include mobile devices that have greater processing capability, longer communication range, and higher bandwidth. Furthermore, the overlay network density may be such that all nodes are always connected, or the network can become disjoint. When the latter is the case, mobile entities can position themselves in order to re-establish connectivity, ensuring network packets reach their intended destination. The NavMote system [6] takes this approach.

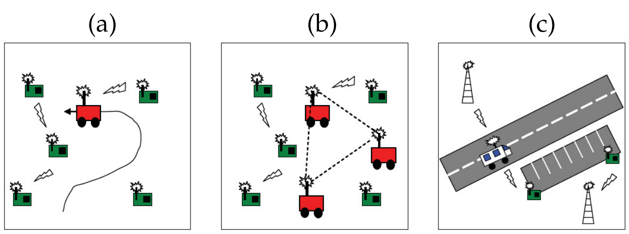

Fig. 1. (a) Planar, (b) 2-Layer, and (c) 3-Layer MWSN architectures

Three Layer. This architecture, a set of stationary sensor nodes pass data to a set of mobile devices, which then forward that data to a set of access points. This heterogeneous network is designed to cover wide areas and be compatible with several applications simultaneously. For example, consider a sensor network application that monitors a parking garage for parking space availability. The sensor network (first layer) broadcasts availability updates to compatible mobile devices (second layer), such as cell phones or PDAs that are passing by. In turn, the cell phones forward this availability data to access points (third layer), such as cell towers, and the data are uploaded into a centralized database server. Users wishing to locate an available parking space can then access the database.

2.2 Node Roles

At the node level, mobile wireless sensors can be categorized based on their role within the network:

Mobile Embedded Sensor. Mobile embedded nodes do not control their own movement; rather, their motion is directed by some external force, such as when tethered to an animal [7] or attached to a shipping container [8]. Typical embedded sensors include [9,10].

Mobile Actuated Sensor. Sensor nodes can also have locomotion capability [11-13]), which enables them to move throughout a sensing region. With this type of controlled mobility, the deployment specification can be more exact, coverage can be maximized, and specific phenomena can be targeted and followed.

Data Mule. Oftentimes, the sensors need not be mobile, but they may require a mobile device to collect their data and deliver it to a base station. These types of mobile entities are referred to as data mules [14]. It is generally assumed that data mules can recharge their power source automatically.

Access Point. In sparse networks, or when a node drops off the network, mobile nodes can position themselves to maintain network connectivity [15]. In this case, they behave as network access points.

3 Mobility Preferences

In many sensor network deployments, an optimal distribution is unknown until the sensor nodes start collecting and processing data. This optimal deployment is generally infeasible without adding mobility. In this section, some of the advantages of adding mobility are addressed.

Long Network Lifetime. Because sensors can move, they will make the transmission more disperse and energy dissipation more efficient so as to get rid of the flaw that sensors near the gateway or sink lose their energy first. In networks that are sparse or disjoint, or when stationary nodes die, mobile nodes can maneuver to connect the lost or weak communication pathways. This is not possible with static WSNs, in which the data from dead or disconnected nodes would simply be lost. Similarly, when network sinks are stationary, nodes closer to the base station will die sooner, because they must forward more data messages than those nodes further away. By using mobile base stations, this problem is eliminated, and the lifetime of the network is extended [16].

More Channel Capacity. Experiments have demonstrated that the capacity gains can be 3–5 times more than static WSNs, if the number of mobile sinks increases linearly with the number of sensors. Mobility also enables greater channel capacity and maintains data integrity by creating multiple communication pathways, and reducing the number of hops messages must travel before reaching their destination [17].

Enhance Coverage and Targeting. Because sensors are mostly deployed randomly instead of precisely, they are generally required to move for better sight or for close proximity which is favorable for targeting. Sensor network deployments are often determined by the application. Nodes can be placed in a grid, randomly, surrounding an object of interest, or in countless other arrangements. In many situations, an optimal deployment is unknown until the sensor nodes start collecting and processing data. For deployments in remote or wide areas, rearranging node positions is generally infeasible. However, when nodes are mobile, redeployment is possible. In fact, it has been shown [15] that the integration of mobile entities into WSNs improves coverage, and hence, utility of the sensor network deployment. This enables more versatile sensing applications as well [5]. For example, an application that monitors wildfires, the mobile sensors are able to maintain a safe distance from the fire perimeter, as well as provide updates to fire fighters that indicate where that perimeter currently is.

Improve Performance. Most networks can be gained improved quality of communications, reduction in overall cost and time to complete task, better security in ad-hoc networks [18], and increase of network capacity [19]. Meanwhile, the aspect of wireless communication is getting more and more important in multi-robot systems [20] to improve their overall performance. To decide its next movement efficiently, a mobile robot may need input data from other robots through wireless interaction. Communication module not only enables data fusion through the sharing of sensor data gathered by mobile robots, but also helps expand an individual view of the network and the physical environment.

Better data fidelity. The last benefit can be attained by utilizing a mobile node to carry data to a destined point. It is useful when wireless channel is in poor condition, or if the premature energy depletion is possible (also called funnelling effect) [21]. The reduced number of hops due to mobility will increase the probability of successful transmissions.

5 Mobile WSNs Challenges

In order to focus on the mobility aspect of wireless sensor networks, it is important to first understand how the common assumptions regarding statically deployed WSNs change when mobile entities are introduced.

Localization. In statically deployed networks, node position can be determined once during initialization. However, those nodes that are mobile must continuously obtain their position as they traverse the sensing region [22]. This requires additional time and energy, as well as the availability of a rapid localization service.

Dynamic Network Topology. Because nodes generally are mobile in MWSNs, the topology is dynamic. New routing and Medium access control (MAC) protocols are needed in MWSNs.Traditional WSN routing protocols, which describe how to pass messages through the network so they will most likely reach their destination, typically rely on routing tables or recent route histories. In dynamic topologies, table data become outdated quickly, and route discovery must repeatedly be performed at a substantial cost in terms of power, time, and bandwidth. Fortunately, there is an active area of research dedicated to routing in mobile ad hoc networks (MANETs), and MWSNs can borrow from this work.

Power Consumption. Power consumption models differ greatly between WSNs and MWSNs. For both types of networks, wireless communication incurs a significant energy cost and must be used efficiently. However, mobile entities require additional power for mobility, and are often equipped with a much larger energy reserve, or have self-charging capability that enables them to plug into the power grid to recharge their batteries.

Mobility of Sink. In centralized WSN applications, sensor data is forwarded to a base station, where it can be processed using resource-intensive methods. Data routing and aggregation can incur significant overhead. Some MWSNs use mobile base stations [16], which traverse the sensing region to collect data, or position themselves so that the number of transmission hops is minimized for the sensor nodes.

6 Mobility Models

Mobility models represent the movement of mobile sensors, and how their location, velocity and acceleration change over time. Since mobility patterns may play a significant role in determining the protocol performance, it is desirable for mobility models to emulate the movement pattern of targeted real life applications in a reasonable way. Such models are frequently used for simulation purposes when new communication or navigation techniques are investigated. *Mobility management* schemes for mobile communication systems make use of mobility models for predicting future user positions. A mobility model should attempt to mimic the movements of real mobile nodes [23]. Changes in speed and direction must occur, and they must occur in reasonable time slots. For example, we would not want mobile nodes to travel in straight lines at constant speeds, because real mobile nodes would not travel in such a restricted manner. In this section, different types of mobility models are described. Mobility models mainly are of four types:

6.1 Random Way Point Mobility Model

The Random Waypoint Mobility Model is a variation of Random Walk model with spatial dependence [23]. It includes pause times between changes in direction and/or speed. A Mobile Node (MN) stays in one location for a certain period of time (a pause time), then MN chooses a random destination(x, y) in the simulation area with parameters such as speed between [0,V_{max}] ,pause time between [P_{min}, P_{max}] that are uniformly distributed. The MN then travels toward the newly chosen destination at the selected speed. Upon arrival, the MN pauses for a specified time period before starting the process again. The value of pauses and speeds is relevant. Fast nodes and long pauses produce a more stable network than slow nodes and short pauses. The most argued issue is that nodes are more likely to be in the central part of the topology rather than close to the bounds [24]. Even though the Random Waypoint model is commonly used in simulation studies, a fundamental understanding of its theoretical characteristics is still lacking. Currently, researchers are investigating its stochastic properties, such as probability distribution of transition length and transition time for each epoch.

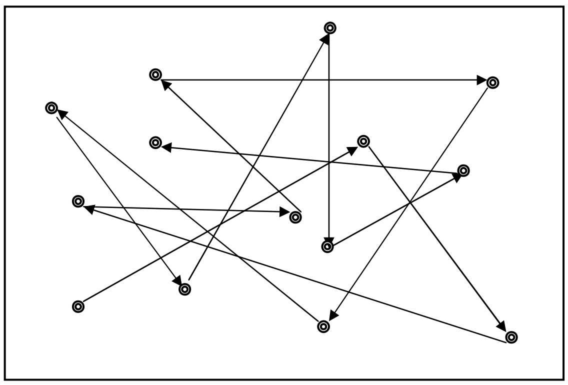

Fig. 2. node movement in the Random Waypoint Model

This model is a memoryless mobility process where the information about the previous status is not used for the future decision. That is to say, the current velocity is independent with its previous velocity and the future velocity is also independent with its current velocity.

6.2 Pathway Mobility Model

One simple way to integrate geographic constraints into the mobility model is to restrict the node movement to the pathways in the map. The map is predefined in the simulation field. Tian, Hahner and Becker et al.[25] utilize a random graph to model the map of city. This graph can be either randomly generated or carefully defined based on certain map of a real city.

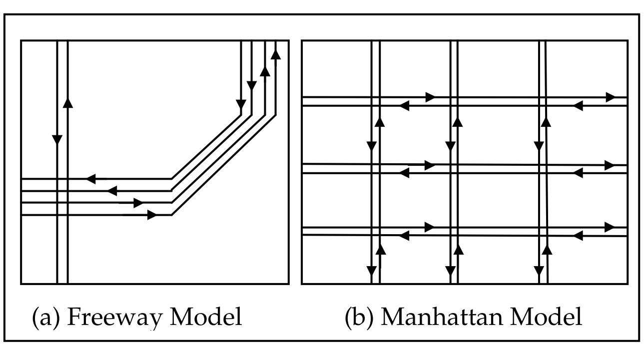

Fig. 3. Freeway and Manhattan model in pathway mobility

Then for each node a destination is randomly chosen and the node moves towards this destination through the shortest path along the edges. Upon arrival, the node pauses for Tpause time and again chooses a new destination for the next movement. This procedure is repeated until the end of simulation. Unlike the Random Way point model where the nodes can move freely, the mobile nodes in this model are only allowed to travel on the pathways. However, since the destination of each motion phase is randomly chosen, a certain level of randomness still exists for this model. So, in this graph based mobility model, the nodes are traveling in a pseudo-random fashion on the pathways. Similarly In this mobility model, the Manhattan mobility model [23] move in horizontal or vertical direction in the terrain. This employs a probabilistic approach in the selection of nodes movements as at each intersection, node can move in left, right or straight in same direction. The probability of taking a left turn is 1/2 and that of right turn is 1/4 in each case. The mobile node is allowed to move along the grid of horizontal and vertical path in the terrain.

6.3 Gauss Markov Mobility Model

Mobility of a node may be constrained and limited by the physical laws of acceleration, velocity and rate of change of direction. Hence, the current velocity of a mobile node may depend on its previous velocity. Thus the velocities of single node at different time slots are 'correlated' [26].

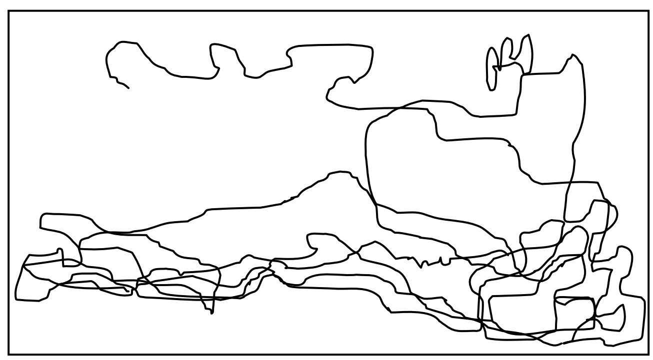

Fig. 4. Traveling pattern of a Mobile node using the Gauss–Markov Mobility Model.

However, the memoryless nature of Random Walk model, Random Waypoint model and other variants render them inadequate to capture this temporal dependency behavior. In the Gauss-Markov model, the temporal dependency plays a key role in determining the mobility behavior [26,27]. This model has temporal dependency with the memory level parameter □. □ is a parameter to reflect the randomness of Gauss-Markov process. The velocity of mobile node is assumed to be correlated over time and modeled as a Gauss Markov stochastic process. When the node is going to travel beyond the boundaries of the simulation field, the direction of movement is forced to flip 180 degree to remain within the simulation field [28].

6.4 Random Point Group Mobility Model

This model exhibits spatial dependency. This model consists groups of nodes that work cooperatively. Each group has a group leader, and number of members. The movement of the group leader determines the mobility behavior of the entire group. Motion of the group leader at time t represented by the vector V_t. Each member of this group deviates from this general motion vector V_t by some degree. For each node, mobility is assigned with a reference point that follows the group movement. The random motion is independent identically distributed random process whose length is uniformly distributed in the interval $[0,r_{max}]$ where r_{max} is maximum allowed distance deviation and the direction is uniformly distributed in the interval $[0,2\pi)$. Since the group leader mainly decides the mobility of group members, group mobility pattern is expected to have high spatial dependence for small values of speed and angle deviation ratio [23].

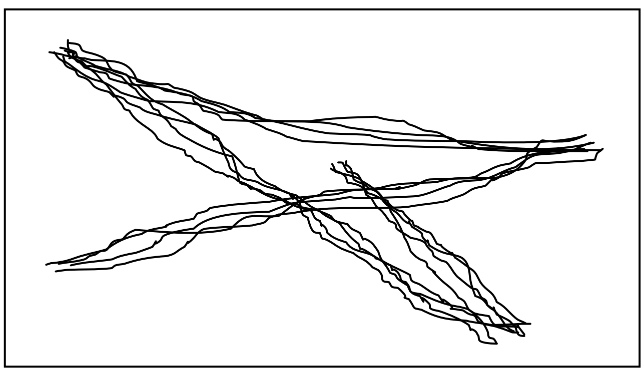

Fig. 5. Traveling pattern of one group (four mobile nodes) using the RPGM model.

The entire field is divided into several adjacent regions. Each region is exclusively occupied by a single group. One such example is battlefield communication. Different groups with different tasks travel on the same field in an overlapping manner. Disaster relief is a good example.

6.5 Summary of Mobility Models

By properly choosing mobility models with different characteristics, we are able to produce set of various mobility scenarios spanning the mobility space. We list the set of mobility models used in the important framework and their characteristics in Table 1.

TABLE 1
THE CHARACTERISTICS OF MOBILITY MODELS USED IN IMPORTANT FRAMEWORK

	Temporal Dependency	Spatial Dependency	Geographic Restriction
Random Waypoint Model	No	No	No
Freeway Mobility Model	Yes	Yes	Yes
Manhattan Mobility Model	Yes	No	Yes
Gauss Markov Mobility Model	No	No	No
Random Point Group Mobility Model	No	Yes	No

7 Conclusion

WSN are still not efficient enough for most applications, even though a lot of research has been done. But mobility is a fundamental factor that influences network protocol performance when mobile sensor nodes are used. Traditional static WSNs have limitations on supporting multiple missions and handling different situations when network conditions change. Introducing mobility to WSNs can significantly improve the network capability and thus release the above limitations. This paper provides an appropriate overview of current researches on mobile wireless sensor networks. Various network structures, advantages, challenges and mobility of mobile sensor networks have been discussed.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks" IEEE Communications Magazine, vol. 40, no. 8, pp. 102–114, 2002.

[2] S. S. Dhillon and K. Chakrabarty, "Sensor placement for effective coverage and surveillance in distributed sensor networks" in IEEE Wireless Communications and Networking Conference, 2003, pp. 1609–1614.

[3] G. Cao, G. Kesidis, T. L. Porta, B. Yao, and S. Phoha, "Purposeful mobility in tactical sensor networks" Sensor Network Operations, 2006.

[4] S.A. Munir, B. Ren, W. Jiao, B. Wang, D. Xie, J. Ma,"Mobile wireless sensor network: Architecture and enabling technologies for ubiquitous computing" In International Conference on Advanced Information Networking and Applications Workshops, vol. 2, pp. 113–120 , 2007.

[5] I. Amundson, X. Koutsoukos, J. Sallai," Mobile sensor localization and navigation using RF doppler shifts" In 1st ACM International Workshop on Mobile Entity Localization and Tracking in GPS-less Environments, MELT 2008.

[6] L. Fang, P.J. Antsaklis, L. Montestruque, M.B. Mcmickell, M. Lemmon, Y. Sun, H. Fang, I. Koutroulis, M. Haenggi, M. Xie, X. Xie," Design of a wireless assisted pedestrian dead reckoning system – the NavMote experience" In IEEE Transactions on Instrumentation and Measurement, vol. 54(6), pp. 2342–2358, 2005.

[7] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. Peh, D. Rubenstein," Energyefficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet" In Proc. of ASPLOS-X, 2002.

[8] B. Kus´y, A. L´edeczi, X. Koutsoukos," Tracking mobile nodes using RF Doppler shifts" In SenSys 2007, Proceedings of the 5th international conference on Embedded networked sensor systems, pp. 29–42. ACM, New York, 2007.

[9] P. Dutta, M. Grimmer, A. Arora, S. Bibyk, D. Culler," Design of a wireless sensor network platform for detecting rare, random, and ephemeral events" In Proc. Of IPSN/SPOTS, April 2005.

[10] J. Polastre, R. Szewczyk, D. Culler," Telos: Enabling ultra-low power wireless research" In Proc. of IPSN/SPOTS, April 2005.

[11] K. Dantu, M. Rahimi, H. Shah, S. Babel, A. Dhariwal, G. S. Sukhatme, "Robomote: enabling mobility in sensor networks" In The Fourth International Symposium on Information Processing in Sensor Networks, IPSN 2005.

[12] J. Friedman, D. C. Lee, I. Tsigkogiannis, S. Wong, D. Chao, D. Levin, W. J. Kaisera, M. B. Srivastava," Ragobot: A new platform for wireless mobile sensor networks" In International Conference on Distributed Computing in Sensor Systems, DCOSS 2005.

[13] S. Bergbreiter, K. S. J. Pister," CotsBots: An off-the-shelf platform for distributed robotics" In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2003.

[14] R. Shah, S. Roy, S. Jain,, W. Brunette," Data mules: modeling a three-tier architecture for sparse sensor networks" In Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications 2003.

[15] G. Wang, G. Cao, T. Porta, W. Zhang," Sensor relocation in mobile sensor networks. In IEEE INFOCOM 2005.

[16] S. Gandham, M. Dawande, R. Prakash, S. Venkatesan," Energy efficient schemes for wireless sensor networks with multiple mobile base stations" In IEEE Global Telecommunications Conference, GLOBECOM 2003.

[17] A. Kansal, A. A. Somasundara, D. D. Jea, M. B. Srivastava, D. Estrin, "Intelligent fluid infrastructure for embedded networks" In Proceedings of the 2nd international conference on Mobile systems, applications, and services (MobiSys), pp. 111–124, 2004.

[18] J. Capkun, J. Hubaux, L. Butty," Mobility helps security in ad hoc networks" In MobiHoc '03 Proceedings of the 4th ACM international symposium on Mobile ad hoc networking & computing, pp 46–56, New York, NY, USA, 2003.

[19] S. Jain, R. C. Shah, W. Brunette, G. Borriello, S. Roy," Exploiting mobility for energy efficient data collection in wireless sensor networks" Mob. Netw. Appl., 11(3), pp. 327–339, 2006.

[20] A. Tiderko, T. Bachran, F. Hoeller, D. S. Rose, "a framework for multicast communication via unreliable networks in multi-robot systems Robot" Auton. Syst, 56(12), pp. 1017–1026, 2008.

[21] J. Li, P. Mohapatra," Analytical modeling and mitigation techniques for the energy hole problem in sensor networks" Pervasive Mob. Comput., 3(3), pp. 233–254, 2007.

[22] J. Rezazadeh, M. Moradi, A. S. Ismail," Efficient localization via Middle-node cooperation in wireless sensor networks" In International Conference on Electrical, Control and Computer Engineering (INECCE, 2011), pp. 410-415, 2011.

[23] F. Bai, A. Helmy, "A Survey of Mobility Modeling and Analysis in Wireless Adhoc Networks" in Wireless Ad Hoc and Sensor Networks, Kluwer Academic Publishers, 2004.

[24] B. Divecha, A. Abraham, et al, "Impact of Node Mobility on MANET Routing Protocols Models"International journal of digital, 2007.

[25] J. Tian, J. Hahner, C. Becker, I. Stepanov, K. Rothermel," Graph-based Mobility Model for Mobile Ad Hoc Network Simulation" in the Proceedings of 35th Annual Simulation Symposium, in cooperation with the IEEE Computer Society and ACM, San Diego, California, April 2002.

[26] B. Liang, Z. J. Haas," Predictive Distance-Based Mobility Management for PCS Networks" In Proceedings of IEEE Information Communications Conference INFOCOM 1999.

[27] T. Camp, J. Boleng, V. Davies," A Survey of Mobility Models for Ad Hoc Network Research" In Wireless Communication and Mobile Computing (WCMC), Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications, vol. 2, no. 5, pp. 483-502, 2002.

[28] N. Meghanathan, "Impact of the Gauss-Markov Mobility Model on Network Connectivity, Lifetime and Hop Count of Routes for Mobile Ad hoc Networks", Journal of networks, Vol. 5, NO. 5, MAY 2010.