A Survey of Sink Mobility Models for Wireless Sensor Networks

[1] Anas Abu Taleb, [2] Tareq Alhmiedat, [3] Osama Al-haj Hassan, [4] Nidal M. Turab
[1,3,4] Department of Computer Science, Isra University, P. O. Box 22, 33, Amman 11622, Jordan
[2] Department of Computer Science, Zarqa University, P. O. Box 132222, Amman 13132, Jordan
[1]anas.taleb, osama.haj, nedalturab}@ipu.edu.jo, [2]t.alhmiedat@zu.edu.jo

ABSTRACT

Using mobile sinks to collect information in wireless sensor networks is an interesting area of research. As a result, a variety of mobility models were proposed by researchers over the years where each mobility model has its own properties that may affect the performance of the network in a way that differs from other models entitled with different properties. In this paper we provide a survey of mobility models that can be used in wireless sensor networks since it is important to provide a classification of the available models. Therefore, several mobility models were reviewed in the proposed work. These models were classified into two main categories namely homogenous and heterogeneous mobility. The goal of the work proposed in this paper is to provide researchers with a clear idea about the available mobility models and their properties. Additionally, we aim to provide researchers with guidelines to help them choose mobility models properly.

Keywords: *Wireless Sensor Networks, Mobile Sink, Group Mobility, Individual Mobility*.

1. INTRODUCTION

Wireless sensor networks (WSNs) consist of a large number of low-cost and small size sensor nodes, which can be embedded in environments in order to accomplish a specific mission by measuring specific parameters such as pressure or temperature. Consequently, WSN has become a vital research area, due to their large potentials in applications including civilian, industrial, agricultural, and military applications. For some applications such as military and industrial, sensor networks are expected to operate in inhospitable environments for periods ranging from days to years without any human intervention [1-7].

Since sensor nodes are battery powered, limited battery power and lifetime are main challenge for these nodes. As a result, many research studies proposed techniques aiming to prolong the life time of sensor networks through reducing the amount of energy consumed by sensor nodes [8-12]. Moreover, sensor nodes consist of three subsystems, namely computing subsystem, sensing subsystem and communication subsystem. According to Patel et. al. [13] the energy consumed by the communication subsystem is several magnitudes higher than that consumed by the computation subsystem and is dependent on the transmission distance and the attenuation exponent.

Consequently, to reduce the transmission distance, multi-hop routing was introduced to deliver the sensed data to the base station, because the transmission distance for each node is smaller than that needed in single-hop. On the other hand, higher delay is introduced by multi-hop routing when compared to single-hop. Thus, the success rate of the network will be affected. Therefore, to solve the above mentioned problems i.e. limited lifetime of sensor nodes and long delays when introducing multi-hop routing, researchers have introduced the use of mobile node or nodes in WSNs. Therefore, these mobile node or nodes can be used to collect data from static sensor nodes thus, reducing the amount of energy required in transmission by static sensor nodes.

It can be concluded that the mobility model adopted by the mobile node or nodes within a sensor network have a great impact on the performance and lifetime of static sensor nodes and the whole WSN. Thus, in this paper we will try to provide a review and a classification of existing mobility models. However, before starting our discussion regarding the existing mobility models, we would like to emphasis on the importance and the impact of mobility models and mobility management on WSNs.

The rest of this paper is organized as follows. In section 2 the importance of mobility models is studied. After that, mobility models are reviewed and classified in section 3. Also, a discussion regarding the studied mobility models is presented in section 4. Finally, the paper is concluded in section 5.

2. IMPORTANCE OF MOBILITY

The main reason for which mobility was introduced in WSNs is to reduce the number of hops required to deliver data from sensor nodes to the base station. Thus, reducing the delay and prolonging the network lifetime by reducing the amount of energy required to send and receive messages. Therefore, it can be concluded that the routing protocol used when introducing mobility to WSNs has a great impact on the network performance [14, 15]. According to Reddy et. al. [14], two schemes must be considered when studying mobility in WSNs namely, location management and handoff management. The former is concerned with rerouting packets while the other focuses on how to use location information of nodes in order to improve the performance of the routing protocol because, node mobility affects nodes positions, route to be followed by messages and information nodes have about their neighborhood.

Another issue to be considered when studying mobility is how to model the mobility pattern adopted by the network. According to [16], two schemes can be considered to model nodes mobility through simulation.

The first scheme is based on collecting information regarding nodes trajectories from real networks then, use the information acquired in the simulation. On the other hand, the second scheme is based on using a mobility model that has specific rules to govern the mobility of nodes in the simulation. However, neither scheme is sufficient to study the effect of mobility models because the first one is based on information collected from a real network and this information might not be available for all researchers, while the results obtained using the second scheme give an indication about the performance of the mobility model that has a certain degree of validity, since studying a network the performance on a real network or on real information is more accurate than simulation.

3. MOBILITY MODELS

Several researches have approached the problem of deploying mobile node or nodes in WSNs in order to prolong the network lifetime and improve its performance. Consequently, some of the proposed models depend on using a single mobile node to collect information from static sensor nodes. On the other hand, there is another category of mobility models that use more than one mobile node in the network. Worth mentioning, the number of mobile nodes used in the models proposed in the second category ranges from two mobile nodes to a sensor network consisting of mobile sensor nodes that move in order to get the best possible coverage and connectivity for the area of deployment. Accordingly, mobility models for WSNs can be mainly classified into two categories Homogenous and Heterogeneous models. The homogenous mobility models depend on having a group of mobile nodes that use the same mobility model to move within the network. However, the heterogeneous models are based on having a single mobile node that moves according to a specified mobility model within the network. Note that the above mentioned categories can be further classified into subcategories as can be seen in Fig. 1.

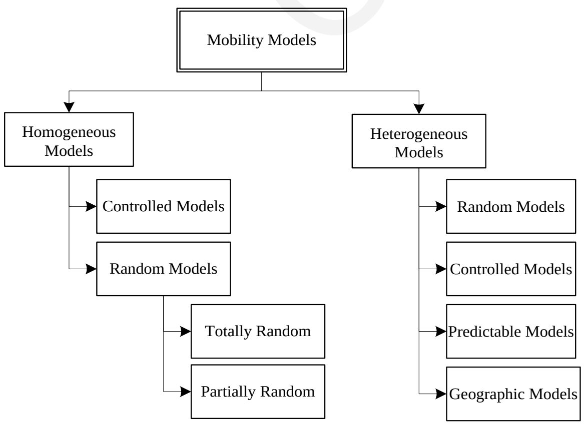

Fig 1: Mobility Models Classification

3.1 Homogenous Mobility Models

As mentioned before, homogenous mobility models are based on having a set of cooperating nodes moving according to a specific model in the deployment area [17]. The number of mobile nodes varies from a subset of sensor nodes deployed in the WSN to having a WSN where all sensor nodes are mobile and moving according to a particular mobility model. From Fig.1, it can be observed that this category can be divided into two main sub categories namely, random models and controlled models. A discussion regarding each sub category can be found in the following sections.

3.1.1 Random Mobility Models

Mobility models that fall under this category can be divided into partially random and totally random. In the former category mobile nodes depend on each other to specify the movement direction [18]. On the other hand, in the totally random models the group of mobile nodes moves in a random direction that is changed periodically.

a. Partially Random

Two mobility models fall under this category namely reference point group mobility model (RPGM) and pursue model. The nodes in the RPGM model are divided into two groups where each group has a leader dedicated to it. In each group the leader is moving randomly according to the random way point mobility model. In other words, the leader chooses a random direction/destination and starts moving towards the selected destination with a random velocity. After arriving to the destination, the leader pauses for a specific period of time. After that, a new destination is selected randomly and the leader starts moving towards it with random speed. The rest of the group members in GPRM, follow the movement of their leader with some deviation [19, 20].

In the pursue mobility model, several nodes try to track and capture a single mobile node that is moving according to the random waypoint model described above. As a result, the seeker nodes are trying to intercept the target node by directing their velocity towards it [21].

b. Totally Random

The mobility models that fall under this category are nomadic mobility model, virtual track-based mobility model, reference velocity group mobility model and structured group mobility model. According to [18, 22] the nomadic mobility model is based on having a group of nodes that moves randomly from one position to another. After that, each node determines its reference point based on the general movement of the group. Inside the group each mobile node moves locally in a Brownian motion.

In the virtual track-based mobility model, each node defines all the possible tracks to a switch station. Then, each node follows a randomly selected track until the destination switch station is visited. Note that this model uses what is called a switch station to model the dynamics of group mobility. Also, the deployed switching stations are connected via several virtual tracks [23]. On the other hand, the reference velocity group mobility model and the structured group mobility model use a set of equations to bond a node’s movement to the positions of a subset of nodes that are members of the same group.

Consequently, the groups of mobile nodes that move according to these mobility models travel randomly within the environment in which these nodes are deployed [24, 25, 26].

3.1.2 Controlled Mobility Models

Column mobility model can be classified under this category. This model is based on having a set of nodes that move in a specified direction. Additionally, every time slot the reference point of every mobile node is updated by the mobile node itself through adding a predefined offset that is used the reference point of the mobile node. When a mobile node is about to cross the boundary of the area being studied, the movement direction is flipped by 180 degree. Note that this model is suitable for searching and scanning activities such as searching and destroying mines [21].

Another model that fall under this category is the group force model. This model can be used to simulate the behavior of a group of nodes that have a common goal such as the same destination or the same velocity. Furthermore, nodes can be classified according to two types of groups namely tight groups and loose groups. In the tight group, nodes movement is interrelated with each other while in the loose group, nodes share a similar factor such as the same destination or they are restricted to be periodically within a specific range of each other. However, in this group nodes move randomly and independently of each other while taking the common goal or restriction into consideration [27].

The autoregressive group mobility model is a two-tier composite model. In the first tier the movement of individual nodes is modeled using an autoregressive model. In the second tier, the group mobility behavior is captured by taking the correlation of nodes mobility into consideration. As a result, the presence of a group is detected by performing a correlation index test on nodes mobility states. In addition, this model has provided a scheme that can be used to estimate a group based mobility where the mobility state of a representative node is used to estimate the mobility state of the group members [28]. Additionally, a coverage oriented mobility model where mobile nodes move towards the area with the lowest coverage within each mobile node neighborhood was proposed in [29].

3.2 Heterogeneous Mobility Models

In heterogeneous mobility model, a mobile node moves independently of any other nodes that may exist in the network. Thus, the mobile node moves according to the adopted mobility model without taking the position and the mobility model adopted by other mobile nodes that may exist in the network into consideration. The model that will be discussed in this section fall under heterogeneous mobility because the network consists of two types of nodes which are static nodes and mobile nodes.

The models that fall under this category can be further classified into four subcategories namely random mobility, controlled mobility, predictable mobility and geographic mobility. A discussion and review of the mobility model that fall under each subcategory can be found in the following subsections.

3.2.1 Random Mobility Models

The Random Way Point model, which is a very simple mobility model, has been presented in [30]. This mobility model is based on dividing the motion of the mobile node into pause periods and motion period. In the pause period, the mobile node will stay in its current position for a specific period of time. However, in the motion period, the mobile node will choose a random direction and will start moving to the new direction with a random speed. After arriving to the new position, the mobile node enters the pause period and stays in that position for the same period of time used in the previous position. Although this model is simple, it suffers from poor choice of velocity distribution and uniform distribution [31].

According to Gloss et. al. [32], along with the random way point model the random direction mobility model is considered the most widely used mobility model for mobile communications research. Similar to the random way point model, the movement of a mobile node is divided into motion periods and optional pause periods. In the motion period, the mobile node is moving in straight segments with constant speed. After a node reaches its destination, it optionally pauses for a specific period of time before selecting a new destination and direction [32]. Moreover there are several approaches that can be used to obtain the new direction for the next walk. The research proposed in [33] presents a model that is based on a cell structure where the mobile node passes the cells in a straight line and can change its movement direction at cells borders. On the other hand, the original model was modified in [34] be allowing a mobile node to change the direction of movement anywhere in the movement area.

Another mobility model that is based on having a mobile node that moves randomly in the area of deployment is called the random walk mobility model. This model was proposed to mimic the unpredictable mobility of entities in the real word. In this model a mobile node chooses a random direction and starts moving in it with a random speed. After a specific period of time or after travelling a specific distance in the chosen direction, a new direction and speed are calculated. Worth mentioning the new direction and speed are calculated from predefined ranges. Furthermore, if the mobile node reaches the boundaries of the deployment or simulation area, it bounces off with an angle that can be determined using the incoming direction. Note that many variations of the random walk mobility model have been proposed such as 1-D and 2-D walks [35].

Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

The research proposed in [36] introduced the concept of data mules that use Random Mobility modes. According to Shah et. al. [36], the sensor network is traversed randomly by the data mules. When a data mule enters the communication range of a sensor node, it collects data from that node.

In order to adapt to different levels of randomness, the Gauss-Markov model was proposed. In this model, each mobile node is assigned a direction and a speed in the initialization phase. After that, based on fixed time intervals of time the movement direction and speed are updated. To elaborate, in addition to a random variable the value of the speed and direction of the (n-1) time interval is used to calculate the value of speed and direction to the n^{th} interval [37]. Note that this calculation is done using the equations presented in [37].

3.2.2 Controlled Mobility Models

In the previous section, we have reviewed random mobility models. Instead of moving mobile nodes randomly, the Controlled Mobility Model was proposed in [38] where the mobile node visits sensor nodes based on a predefined schedule that is built based on the sampling rate of sensors and event occurrence rate. Additionally, when building such schedule, the time between two consecutive visits for the same sensor node must be taken into account. In other words, the time between two consecutive visits must not be too long so that, sensor nodes will not suffer from buffer overflow.

A decentralized mobility model for data collection was proposed in [39]. The purpose of the research proposed in [39] is to collect data from sensor nodes through coordination of decentralized mobile nodes. Therefore, two mobility models were proposed to manage the movement of mobile nodes. In addition, bidding strategies were used in order to schedule data collection requests and to determine the winner. Moreover, the research proposed in [17] introduced an algorithm to calculate mobility patterns for mobile nodes using cluster formation and artificial potential functions. In order to calculate the mobility models, the artificial potential function uses two schemes namely; potential field and particle based.

A sensor network with mobile agents (SENMA) architecture was proposed in [40] where the use of stationary sensor nodes is combined with the use of mobile and more resource rich nodes. The main idea of the proposed architecture is to shift the computation burden from the stationary sensor nodes to the mobile nodes because the mobile nodes have more processing power than the stationary sensor nodes. Furthermore, it is assumed that the mobile nodes might be manned or unmanned vehicles that might collect data by moving on the ground or aerially. Moreover, these mobile agents are not present all the time in the network, in other words, they will be operational when there is a need to collect data from stationary sensor nodes.

3.2.3 Predictable Mobility Models

In this section, predictable mobility models are reviewed. Note that using predictable mobility models can prolong the network lifetime as sensor nodes can go to sleeping or power saving mode when the mobile element is not expected to be in its proximity. The research proposed in [41] introduced a Predictable Mobility model where sensor nodes know the path that will be used by the mobile sink. Thus, to save energy, a sensor node enters sleep mode until the predicted time for data transfer. After that, the sensor node goes to active mode and starts sending its data to the mobile sink.

Additionally, the work proposed in [42] has extended the Gauss-Markov model in order to be able to predict the next location of the mobile node. To be specific, the locations of the n previous visits have been incorporated when calculating the new location and speed of the mobile sink. Moreover, an algorithm to predict the next location of the mobile sink was proposed. This algorithm is based on using a transition matrix that contains the previous locations that have been visited by the mobile node. After having the information of the last n visits stored in the prediction matrix, the algorithm used information regarding the last two visits to predict the next location of the mobile sink [42].

A statistical approach for mobility prediction was proposed in [43]. The proposed approach consists of two techniques namely, a wheeled vehicle model and a stochastic response surface method. The former model is used to calculate the interaction forces within the environment while the later method is used to compute uncertainty propagation using the determination of a statistically equivalent reduced model. After that, the statistically reduced model can be used to determine statistical properties, such as position and orientation, which can help in predicting the mobility of the mobile node.

3.2.4 Geographic Mobility Models

Another way to control the mobility of mobile nodes is to restrict the motion according to geographic nature of the environment in which a mobile node or sink is deployed. In such models, the presence of obstacles and other constrains such as reaching the end of a path or reaching the boundaries of the environment being studied are taken into consideration by the mobile sinks.

In this section four geographically based mobility models are reviewed namely, pathway mobility model, freeway mobility model, Manhattan mobility model and obstacle mobility model.

In the pathway mobility model, the geographic constraints can be easily integrated into the adopted mobility model by restricting the movement of the mobile node to predefined pathways in the map that represents the deployment environment. The map that represents the deployment environment can be generated in two ways. The first method is based on generating the map randomly.

Vol. 4, No. 9 September 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

On the other hand, the map can be defined carefully to represent a real city. In both ways the vertices in the map represent the buildings in a city and the edges represents paths or streets linking the buildings which can be used to move from one building to another. In the beginning, a mobile node is deployed randomly on the edges. After that, a destination is selected randomly by the mobile node. Then, the mobile node starts moving towards the randomly selected destination through the shortest path along the edges. When the mobile node reaches its destination, it pauses for a specific period of time next a new destination is selected randomly. So, it can be concluded that in the pathway mobility model a mobile node moves in a pseudo-random fashion since a mobile node randomly selects a random destination from a predefined set of vertices [21, 44].

The second mobility model being reviewed in this section is the freeway mobility model. According to [45], the movement of mobile nodes in a freeway can be emulated using the free way mobility model. This model assumes that a freeway consists of one or more lanes where a mobile node can move in both directions in each lane. Furthermore, the movement of the mobile node is restricted to a specific lane without being able to change it. Additionally, the velocity of the mobile node time instant t is calculated based on the node's velocity at time instant t-1. Moreover, if two mobile nodes exist on the same lane i.e. node1 is behind node2, the velocity of node1 is controlled to be less than that of node2 in order to maintain the safety distance between the mobile nodes.

In order to model movement in urban areas, the Manhattan mobility model was proposed. This model is based on a grid road topology where streets are organized vertically and horizontally. As a result, mobile nodes movement is restricted to the organization of the streets. In other words, mobile nodes can only move horizontally and vertically. Worth mentioning a mobile node can only change its direction at the intersection points of the streets. For example, if node1 is moving vertically, it cannot change its movement direction until it reaches an intersection point. When node1 reaches streets intersection point, it can choose whether to keep on moving vertically or to change the movement direction in order to move horizontally i.e. turn left or right. Additionally, the velocity of a mobile node at an instant of time depends on its velocity in the previous instant of time. Moreover, similar to the freeway model the velocity of a mobile node is also restricted by the proceeding mobile node existing on the same street or lane in order to maintain a safety distance [46].

The obstacle mobility model takes into consideration the presence of obstacles in the movement path of a mobile node. Therefore, a mobile node has to change or modify its path in order to detour around the obstacle it is facing. Consequently, it can be concluded that the presence of obstacles in a mobile node's trajectory has several effects on the behavior of the mobile node. Additionally, obstacles do affect the signal propagation for example; in indoor applications signals suffer severe attenuation because of the presence of obstacles [21]. Thus, the research in [47] proposed three realistic mobility scenarios that take the presence of obstacles into consideration. These scenarios are conference scenario, event coverage scenario and disaster relief scenario. In these three scenarios, obstacles were in the form of rectangular boxes that were placed randomly in environment being studied. A mobile node has to find a movement path that avoids the deployed obstacles. In addition, the obstacles are considered to be capable of fully absorbing signals running through them. Furthermore, the link between two nodes is considered broken if an obstacle exists between them [21].

4. DISCUSSION

In this paper several random mobility models have been reviewed. Some of the reviewed models were classified as homogenous/group mobility models while others were classified as heterogeneous/individual models. However, regardless of being classified as group or individual mobility model most random mobility models have similar properties. Additionally, all the reviewed models were proposed to mimic the motion of humans, vehicles or animals in real life applications were the motion of a mobile entity cannot be controlled or predicted. Furthermore, these random models provide a simple way to imitate the behavior of several mobile entities. On the other hand, certain mobility characteristics regarding realistic scenarios, such as temporal dependency of velocity, spatial dependency of velocity and geographic restrictions of movement, may not be captured effectively by the random models [21].

Temporal dependency of velocity and spatial dependency of velocity characteristics may not be adequately captured because, the velocity of a mobile node at a certain instant is completely independent of the node's velocity at the pervious instant, which results in the occurrence of some extreme behaviors regarding mobility such as sudden stop and acceleration. On the other hand, some random mobility models, such as Gauss-Markov, have the ability to capture the temporal dependency of velocity. In these models the velocity of a mobile node is calculated based on the node's previous velocity. Furthermore, some mobility models were proposed in order to capture the spatial dependency characteristic such as reference point group mobility, pursue mobility and nomadic mobility model where, mobile nodes move in a group or independently as individuals. However, in these models each mobile node moves according to the movement or the position of the group leader or other neighboring nodes [21].

In addition, in random mobility models a mobile node can move freely in the area of deployment without taking the presence of obstacles into account. However, taking the presence of obstacle is important for some realistic applications such as urban areas and battle fields. Therefore, random mobility models may not effectively capture the geographic restrictions of the movement [21].

Vol. 4, No. 9 September 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

As a result, geographic based mobility model were proposed to account for the presence of obstacles in the trajectory of a mobile node.

Another category of mobility models is controlled mobility. In these models the movement of mobile nodes is restricted to be within lanes or columns such as columns mobility model. Additionally, mobile nodes within the area of deployment take into consideration the movement of other mobile nodes that are members of the same group or may exist on the same column. Consequently, the motion direction of a mobile node is controlled by movement direction of the group or the group leader. Furthermore, the velocity of a node is affected by the velocity of the node preceding it in order to avoid collisions of mobile node.

Using controlled mobility can improve the overall performance of the sensor network. However, sensor node might suffer from buffer overflow while waiting for the mobile sink to be in its communication range. Also, the energy of a sensor node or nodes might get depleted because of being active while the mobile sink is far away. Another reason for energy depletion is that a node might spend most of its energy forwarding packet originated from other sensor nodes to the mobile sink when multi-hop routing is used. Thus, predictable mobility models were proposed. In these models a sensor node can go to sleep mode or power saving mode in order to save its energy. When the mobile sink is expected to be near a sensor node, the sensor nodes starts up and become active in order to report the information it has collected to the mobile sink.

To capture the geographic restrictions of movement, the geographically based mobility model, such as pathway, freeway, Manhattan and obstacle mobility models, take into consideration the presence of obstacle in the trajectory of the mobile node and provide techniques to give the mobile node the ability to overcome any obstacle it is facing. Hence, these models are based on creating a map that represents a city and its street where the mobile nodes can move on the streets. The map representing the city can be randomly generated or can be carefully designed. For example Manhattan mobility model is based on creating a grid that represents the city and the mobile node can only move on the streets or edges linking the grid points. Additionally, a mobile node cannot change its movement direction unless it reaches an intersection point of street where it can change its direction.

As a result, it can be concluded that these models are based on representing the area being studied by a graph or a map. In this graph the paths or streets are represented by edges while buildings or obstacles are the nodes of this graph or map. Table 1 summarizes the mobility categories and the models classified under each category.

Table 1: Mobility Models

Model Main Category	**Model Subcategory**	**Model Name**
Homogenous	Random Mobility	Reference Point Group Mobility
		Pursue Model
		Nomadic Model
		Virtual Track-based Mobility
		Reference Velocity Group Model
		Structured Group Mobility Model
	Controlled Models	Column Model
		Group Force
		Auto Regressive Model
Heterogeneous	Random Models	Random Way Point Model
		Random Direction Model
		Random Walk Model
		Gauss-Markov Model
	Controlled Models	[37, 38, 39]
	Predictable Models	[40, 41, 42]
	Geographic Models	Pathway Model
		Freeway Model
		Manhattan Model
		Obstacle Model

Hence, it can be concluded that homogenous mobility models can be used when there is a need to change the network topology in order to achieve the best coverage and connectivity of the environment while, heterogeneous mobility models can be used when it is necessary to have a mobile sink or sinks that move within the network in order to collect information from static sensor nodes. Additionally, random mobility models are suitable to be used when there is a need for simulating the behavior of humans, animals and vehicles where collecting information about temporal dependency of velocity, spatial dependency of velocity and geographic restrictions is not required. Conversely, controlled and geographic mobility models can be used when mobile nodes are required to be confined within the area of deployment of the network and when the movement of mobile nodes is constrained by certain properties of environment such as the presence of obstacles. Furthermore, predictable models can be used when there is a need to conserve the energy consumption of static sensor nodes where sensor nodes keep switching between power saving mode and active mode.

5. CONCLUSION

The use of mobile nodes in WSNs plays an important role in improving the overall performance of the network. Thus, the importance of choosing a mobility model and the effect of mobility on WSNs was presented in order to clarify the motivation behind presenting the work proposed in this paper and to give researchers an idea on how to choose a mobility model that suite their needs. In addition, in this paper various mobility models were reviewed and classified. The studied mobility models were classified into two main categories; homogenous/group mobility and heterogeneous/individual or entity mobility. Furthermore, both categories were further divided into subcategories in order to categorize each studied mobility model properly. Finally, a discussion regarding the reviewed model was provided.

REFERENCES

[1] Jiang, P. "A New Method for Node Fault Detection in Wireless Sensor Networks." Sensors Vol. 9, no. 2 pp. 1282-1294, 2009.

[2] Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., and Anderson, J. , "Wireless Sensor Networks for Habitat Monitoring," In Proceedings of the 1st international ACM Workshop on Wireless Sensor Nerworks and Applications, pp. 88-97, Atlanta, Georgia, USA, September 2002.

[3] Hamdi, M., Boudriga, N., and Obaidat, M. S., "WHOMoVeS: An optimized broadband sensor network for military vehicle tracking," International Journal of Communication Systems, Vol. 21 , Issue 3, pp. 277-300, 2008.

[4] Son, B., Her, Y., and Kim, J., "A design and implementation of forest-fires surveillance system based on wireless sensor networks for South Korea Mountains." International Journal of Computer Science and Network Security.(IJCSNS), Vol. 6, Issue 9, pp. 124–130, 2006.

[5] Antoine-Santoni, T., Santucci, J. F., De Gentili, E., Silvani, X., and Morandini, F. "Performance of a protected wireless sensor network in a fire. Analysis of fire spread and data transmission." Sensors 9, no. 8, pp. 5878-5893, 2009.

[6] Lloret, J., Garcia, M., Bri, D., and Sendra, S. "A Wireless Sensor Network Deployment for Rural and Forest Fire Detection and Verification." Sensors Vol. 9 Issue: 11. pp. 8722-8747 October 2009.

[7] Resch, B., Mittlboeck, M., Girardin, F., Britter, R. and Ratti, C. "Real-time Geo-awareness - Sensor Data Integration for Environmental Monitoring in the City." In Proceedings of the IARIA International Conference on Advanced Geographic Information Systems & Web Services. GEOWS'09. pp. 92-97, Cancun, Mexico, February 2009.

[8] Min, R., and Chandrakasan, A.," Energy-efficient communication for ad-hoc wireless sensor networks." Conference Record of the Thirty-Fifth Asilomar Conference on Signals, Systems and Computers. Vol. 1, pp. 139–143, IEEE 2001.

[9] Pottie, G.J., "Wireless sensor networks." In Information Theory Workshop, pp. 139–140, IEEE 1998.

[10] Salhieh, A., Weinmann, J., Kochha, M., and Schwiebert, L., "Power efficient topologies for wireless sensor networks." In International Conference on Parallel Processing, pp. 156–163, IEEE 2001.

[11] Min, R., Bhardwaj, M., Cho, S. H., Sinha, A., Shih, E., Wang, A., and Chandrakasan, A., "An architecture for a power-aware distributed microsensor node." In IEEE Workshop on Signal Processing Systems, pp. 581–590, IEEE 2000.

[12] Estrin, D., "Wireless sensor networks: Application driver for low power distributed systems." In International Symposium on Low Power Electronics and Design, pp. 194-194, ACM 2001.

[13] Patel, K., Patel, C., Rizvi, S. S., and Elleithy, K. M., "An Efficient Approach to Reduce the Energy Consumption in Wireless Sensor Networks through Active Nodes Optimization," Nefor Engineering Education Confernce, April 2007.

[14] Reddy, B. V. R., and Hoda, M. N., "Study of Mobility Management Schemes in Mobile Adhoc Networks", International Journal of Computer Applications, Vol. 17, No. 7, pp 975-8887, March 2011.

[15] Hietalahti, M., and Särelä, M., "Security Topics and Mobility Management in Hierarchical Ad Hoc Networks: A Literature Survey", Helsinki University of Technology Laboratory for theoretical Computer Science, April 2004.

[16] Hossmann, T., "Mobility Prediction in MANETs", PhD Dissertation, Master's Thesis, Swiss federal institute of technology, Zurich, 2006.

[17] Sikora, A., and Niewiadomska-Szynkiewicz, E., “Mobility Model for Self-Configuring Mobile Sensor Network”, The fifth International conference on sensor technologies and applications (SENSORCOMM 2011), pp. 97-102, France, August 2011.

[18] Vasanthi, V., Romen Kumar, M., Ajith Singh, N., and Hemalatha, M., “ A Detailed Study of Mobility Models in Wireless Sensor Networks,” Journal of Theoretical and Applied Information Technology, Vol. 33, No. 1, pp. 7-14, 2011.

[19] Hong, X., Gerla, M., Pei, G., and Chiang, C. C., “ A Group Mobility Model for Ad Hoc Wireless Networks”, . In Proceedings of the 2nd ACM international workshop on Modeling, analysis and simulation of wireless and mobile systems, pp. 53-60, ACM 1999.

[20] Jayakumar, G., and Ganapathi, G., “Reference point group mobility and random waypoint models in performance evaluation of MANET routing protocol”, Journal of Computer Systems, Networks and Communications, Vol. 13, No. 3, 2008.

[21] Bai, F., and Helmy, A., “A Survey of Mobility Models in Wireless Adhoc Networks”, University of Southern California, USA 206, 2004.

[22] Borrel, V., De Amorim, M. D., and Fdida, S., “On natural mobility models.” In Proceedings of the Second international conference on Autonomic Communication (WAC'05), pp. 243-253 Springer-Verlag, Berlin, Heidelberg, 2006.

[23] Sacko, D., Benxiong, H., Furong, W., and Khider, I., “A Survey of group merge and split mobility models”, Ubiquitous Computing and Communication Journal, Vol. 2, No. 5, October 2007.

[24] Musolesi, M., and Mascolo, C., "Mobility models for systems evaluation." In Middleware for Network Eccentric and Mobile Applications, pp. 43-62. Springer Berlin Heidelberg, 2009.

[25] Blakely, K., and Lowekamp, B.,” A structured group mobility model for the simulation of mobile ad hoc networks”. In Proceedings of the second international workshop on mobility management and wireless access protocols, pp. 111–118, New York, NY, USA, ACM 2004.

[26] Wang, K., H., and Li, B., “Group mobility and partition prediction in wireless ad-hoc networks”. In IEEE International Conference on Communications, 2002. ICC 2002. Vol. 2, pp. 1017-1021, IEEE, 2002.

[27] Williams, S., A., and Huang, D., "A group force mobility model." Simulation Series 38, no. 2, 333, 2006.

[28] Roy, R. R. ,”Autoregressive Group Mobility Model”, in Handbook of Mobile Ad Hoc Networks for Mobility Models, pp. 791-806, Springer, 2011.

[29] Ben Ayed, S., Hamdi, M., Boudriga, N., “DPRMM: A Novel Coverage-Invariant Mobility Model for Wireless Sensor Networks,” In Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008, pp. 1-5, IEEE 2008.

[30] Divecha, B., Abraham A., Grosan, C., and Sanyal, S., “Impact of Node Mobility on MANET Routing Protocols Models,” Journal of Digital Information Management, Vol. 5, no. 1, pp. 19-24, 2007.

[31] Yoon, J., Liu, M., and Noble, B., “Random waypoint considered harmful.” In INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies. Vol. 2, pp. 1312-1321. IEEE 2003.

[32] Gloss, B., Scharf, M., and Neubauer, D., "A more realistic random direction mobility model." TD (05) 52, 13-14, 2005.

[33] Hong, D., and Rappaport, S. S., “Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Nonprioritized Handoff Procedures,” In IEEE Transactions on Vehicular Technology, vol. 35, no. 3, pp. 77–92, August 1986.

[34] Guerin, R., A., “Channel Occupancy Time Distribution in a Cellular Radio System,” IEEE Transactions on Vehicular Technology, vol. 35, no. 3, pp. 89-99, August. 1987.

[35] Aslam, M., Z., and Rashid, A., "Comparison of Random Waypoint & Random Walk Mobility Model under DSR, AODV & DSDV MANET Routing Protocols." arXiv preprint arXiv:1104.2368, 2011.

[36] Shah, R., C., Roy, S., Jain, S., and Brunette, W., “Data MULEs: Modeling a Three-Tier Architecture for Sparse Sensor Networks.” IEEE Workshop Sensor Network Protocols and Applications (SNPA .03) May 2003.

[37] Camp, T., Boleng, J., and Davies, V., "A survey of mobility models for ad hoc network research." Wireless communications and mobile computing 2, no. 5, pp. 483-502, 2002.

[38] Somasundara, A., A., Ramamoorthy, A., and Srivastava, M., B., “Mobile Element Scheduling for Efficient Data Collection in Wireless Sensor

Networks with Dynamic Deadlines." In Proceedings pf the 25th IEEE International Real-Time System Symposium, pp. 296-305, IEEE 2004.

[39] Hanoun, S., Creighton, D., and Nahavandi, S., "Decentralized mobility models for data collection in wireless sensor networks," In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA '08), pp. 1030–1035, May 2008.

[40] Tong, L., Zhao, Q., and Adireddy, S., "Sensor Networks with Mobile Agents," In Military Communications Conference, 2003. IEEE MiLCOMM'03, pp. 688-693, Boston, MA, October 2003.

[41] Chakrabarti, A., Sabharwal, A., and Aazhang, B., "Using Predictable Observer Mobility for Power Efficient Design of Sensor Networks," In Proceedings of the 2nd International Workshop on Information Processing in Sensor Networks, pp. 129-145, Springer Berlin Heidelberg, 2003.

[42] Gambs, S., Killijian, M., O., and del Prado Cortez, M., N., "Next place prediction using mobility Markov chains." In Proceedings of the First Workshop on Measurement, Privacy, and Mobility, p. 3. ACM, 2012.

[43] Ishigami, G., Kewlani, G., and Iagnemma, K., "Statistical mobility prediction for planetary surface exploration rovers in uncertain terrain." In 2010 IEEE International Conference on Robotics and Automation (ICRA), pp. 588-593. IEEE, 2010.

[44] Tian, J., Hahner, J., Becker, C., Stepanov, I., and Rothermel, K., "Graph-based mobility model for mobile ad hoc network simulation." In Proceedings of the 35th Annual Simulation Symposium, pp. 337-344. IEEE, 2002.

[45] Meghanathan, N., "A simulation study on the impact of mobility models on the network connectivity, hop count and lifetime of routes for ad hoc networks." Informatica: An International Journal of Computing and Informatics, Vol. 34, no. 2, pp 207-221, 2010.

[46] Buruhanudeen, S., Othman, M., and Ali, B., M., "Mobility models, broadcasting methods and factors contributing towards the efficiency of the MANET routing protocols: Overview." In International Conference on Communications, 2007. ICT-MICC 2007, pp. 226-230. IEEE, 2007.

[47] Johansson, P., Larsson, T., Hedman, N., Mielczarek, B., and Degermark, M., "Scenario-based performance analysis of routing protocols for mobile ad-hoc networks." In Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking, pp. 195-206. ACM, 1999.

AUTHOR PROFILES

Dr. Anas Abu Taleb is an assistant professor in the department of Computer Science at Isra University, Amman, Jordan. He received a Ph.D. in Computer Science from the University of Bristol, UK, 2010, MS.c. in Computer Science from the University of the West of England, UK, 2007 and BS.c. degree in Computer Science from Princess Sumaya University for Technology, Jordan, 2004. Dr. Abu Taleb has published several journal and conference papers in sensor networks. In addition to sensor networks, Dr. Abu Taleb is interested in network fault tolerance, routing algorithms, and cloud computing.

Dr. Tareq Alhmiedat is an assistant professor in Computer Science Department at Tabuk University. He received a Ph.D. in Computer Science from Loughborough University, Loughborough, UK, 2009. MSc in Software Engineering from the University of the West of England, Bristol, UK, 2006, and a BSc degree from Applied Science University, 2004. His research interests including tracking mobile targets through Wireless Sensor Networks, Robotic Systems, and Home automation and remote control applications.

Dr. Osama Al-haj Hassan obtained his BSc in Computer Science from Princess Sumaya University for Technology (PSUT). He also received his MSc in Computer Science from New York Institute of Technology (NYIT). He obtained his PhD in Computer Science from University of Georgia (UGA). Currently, he is an Assistant Professor at Isra University in Jordan. His research interests are in distributed systems, web services, Web 2.0, caching and replication techniques, peer-to-peer networks and event based systems.

Dr. Nidal Turab received his BSc degree in communication engineering from university of Garounis, Benghazi, Libya 1992 and M. Sc. in Telecommunication Engineering from University of Jordan, Amman, Jordan, 1996. Ph.D. in Computer Science. Polytechnic University of Bucharest, Faculty of Automatic Control and Computers, 2008. His research interests including Wireless Networks Security Issues, cloud computing, Encryption and Decryption Systems. Networking security. Currently, He is working at Isra University as an assistant Prof.