Increasing the lifetime of hexagonal deployed Wireless Sensor Web Network

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Abstract: **Like with Wireless Sensor Networks (WSN) there are two main goals of Sensor Web: the optimal deployment of sensor nodes, and the maximization of sensor network lifetime. They are particularly important considering critical event applications, like residential fire detection, because of the fact that the topology of sensor nodes and the network lifetime have a dramatic impact on the overall network effectiveness and the efficiency of its operation. One of the possible solutions may be the development of an appropriate algorithm for minimizing the expected energy consumption as a function of specific sensor nodes topology. In this paper we have analyzed a hexagonal sensor deployment scheme and proposed specific algorithm for energy saving by scheduling specific active-passive pattern of sensor nodes.**

I. INTRODUCTION

A sensor node in WSN is a small embedded computing device that interfaces with sensors/actuators and communicates using short-range wireless transmitters. It has limited battery resources, processing and communication capabilities. Sensors nodes form a logical network in which data packets are routed hop-by-hop towards management nodes, typically called sinks or base stations. Thus, a WSN comprises a potentially large set of nodes that may be distributed over a wide geographical area, indoor or outdoor. Recent advances in WSN technology and the use of the Internet Protocol (IP) in resource constrained devices has radically changed the Internet landscape creating a new form called Internet of Things (IoT) [1]. The IoT will connect physical (analogic) environments to the (digital) Internet, unleashing exciting possibilities and challenges for a variety of application domains, such as smart metering, e-health logistics, building and home automation [2]. One of the most important building elements of IoT are sensor nodes, precisely, a Sensor Web. Traditionally, Sensor Web is defined as a web of interconnected heterogeneous sensors that are interoperable, intelligent, dynamic, flexible and scalable. This definition implies that a Sensor Web is a hardware network of sensors. Alternatively, the Sensor Web can be defined as a universe of network - accessible sensors, sensory data and information [3]. In other words, the concept of the Sensor Web reflects such a kind of infrastructure for automatically discovering and accessing appropriate information from heterogeneous sensor devices over the Internet.

The design of a wireless Sensor Web platform must deal with challenges in energy efficiency, cost, and application requirements. Choice of deployment strategy, which is a first step in forming any WSN, depends on applications, requirements and design goals [4]. Sensors can generally be deployed in an area of interest either deterministically or randomly. The choice of the deployment scheme highly depends on the type of sensors, application and the environment that the sensors will operate in. In other words, the node's position determines the functionality, life span and the efficiency of the network. Using deterministic deployment strategy, the access to the monitored field must be granted and the number of required nodes for full converge could be determined. Therefore, it is suitable for optimal deployment where the coverage and/or the sensor networks lifetime are maximized. In addition, the number of the required sensors to monitor a given area in a deterministic deployment, in most cases, is more efficient [4, 5]. There are many deterministic deployment strategies presented in literature: square [6], triangular [7, 8], strip [8, 9], hexagonal [10, 11, 12]. As the WSNs are made up of tiny energy hungry sensor nodes, it is a challenging process to retain the energy level of those nodes for a long period. Therefore it is necessary to extend the battery life of individual sensors so that the network can remain functional as long as possible. In the above mentioned topologies, the number of neighboring nodes determines the number of receivers and hence results in more overall power usage, even though the number of transmissions decreases. Thus, there is a fundamental trade-off between decreasing the number of transmissions and increasing the number of receptions [13]. In [14] authors consider the topology that best supports communication among sensor nodes. They consider different routes and topologies, demonstrating the difference in performance and explaining the underlying causes. Proposing a power-aware routing protocol and simulating the performance, authors show that their routing protocol adapts routes to the available power what leads to a reduction in the total power used as well as more even power usage across nodes. Energy awareness, power management and data dissemination considerations have made routing in WSN a challenging issue. Low latency data delivery is an important requirement for achieving effective monitoring through WSNs. The paper [15] propose a forwarding protocol based on biased random walks where nodes use only local information about neighbors and their next active period to make the forwarding decisions. This is referred as lukewarm forwarding. Analytical and simulation experiments make it possible to reduce the latency without increasing the number of transmissions needed to deliver the message to destination.

In this paper the performance issues associated with hexagonal Sensor Web network topology applied in fire detection are analyzed. Application in fire detection requires accurate deployment of the sensors. In addition, many parameters need to be considered during the deployment process for efficient network operation. Since the topology in this case is fixed and known, it is assumed that the base station position can be optimally determined. Thus, the power requirements for communicating with the base station should be essentially independent of the topology. The ultimate objective of the practical design in this paper can be defined as follow: For a specific sensing task – early and accurate smoke detection, determine how the number, deployment and scheduling of smoke detectors into hexagonal structure influence on the network energy consumption and lifetime. For the purpose of the paper the variant of active-passive scheduling is considered with the aim to reduce energy consumption and thus increase network lifetime.

II. Hexagonal deployment of sensor nodes

A grid-based deployment is considered as a good deployment in WSNs, especially for the coverage performance. There are several grid based designs like as unit square, equilateral triangle, regular hexagon etc [16]. In this paper the hexagon grid deployment pattern with "r" communication range is chosen for the evaluation purposes (Fig. 1).

Figure 1. Hexagonal deployment strategy [11]

The easiest way to detect a fire at residential places is by using the smoke sensors that are usually sensitive to ionization or obscuration. The room with dimensions 50x19x4 *m*, with a flat ceiling and with the average fire risk and medium fire load is observed for simulation purpose. It is assumed that there are no physical partitions and barriers in the monitored room that may affect the deployment process as well as the operation of sensor networks. In monitoring applications, like fire detection, sensors must be positioned so that every point in the region of interest is monitored by at least one sensor. A sensor is able to monitor all points within a certain distance of its location, i.e., a disk of radius "r". This paper is focussed on finding the deployment with minimal number of sensor nodes whose centralized disk completely covers given area. The underlining Hexagonal deployment of smoke sensors used is presented in Fig. 2.

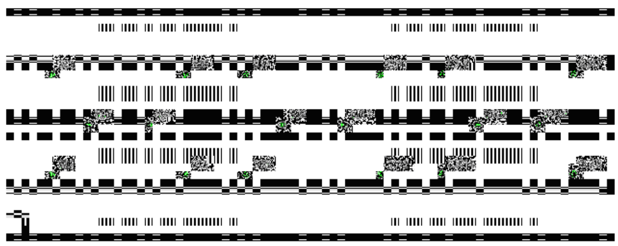


Figure 2. Hexagonal deployment strategy of smoke sensors

Fig. 3 shows that, with sensor nodes placement for r=5, above mentioned requirements are fulfilled and 100% coverage of the room is achieved meeting the crucial requirements in the case of fire presence.

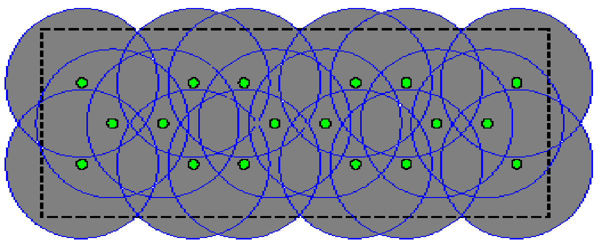


Figure 3. Coverage obtained by hexagonal deployment of smoke sensors

III. Optimization of active sensor nodes number

Acquisition of precise data and immediate transfer of the data to sink node is very important, especially in fire detection. Data processing and data transfer require more power. When, the data has to be transferred and when, it needs to be stored, depends on the state of the radio in the node. To conserve energy, the radio can be switched to sleep state when there is no data to send or receive. This method of switching the radio to a sleep state and making it active if any event is detected is well known as on-demand scheme or event-based scheme. There is an another method of scheduling based on regular time interval for switching all the nodes either in sleep or active mode known as synchronous scheme. There is no need to keep all the nodes active at the same time. WSN can follow a scheduling pattern, accordingly, at any instant; only a limited number of nodes can be active [13].

The work presented in this paper considers two cases based on the same principle and presented scheduling protocol will keep only a subset of nodes to be in active state and keeping others inactive or in passive state. A scheduling protocol will be the best if it keeps only a minimum number of nodes active at any instant. In this paper is proposed that for critical application monitoring only half of sensors should be active, according to Fig. 4 and Fig. 6.

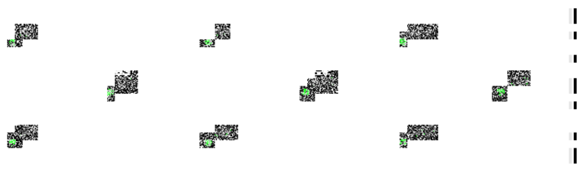


Figure 4. 1st modified hexagonal deployment strategy (hex-1)

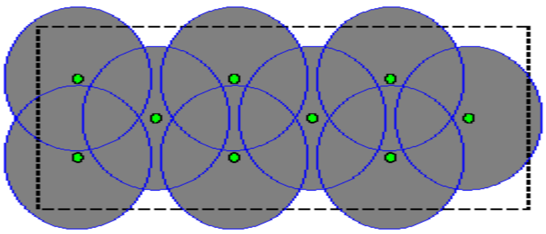


Figure 5. Coverage obtained by active sensors of 1st modified hexagonal deployment of smoke sensors

Figure 6. 2nd modified hexagonal deployment strategy (hex-2)

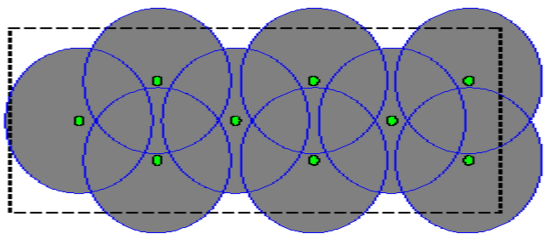


Figure 7. Coverage obtained by active sensors of 2nd modified hexagonal deployment of smoke sensors

From Fig. 5 and 7 is obvious that in those two cases full coverage of room is not achieved what can lead to late detection of fire, especially if it is located out of detection zones.

To avoid the situation of the late detection in areas outside of detection zones, it is necessary to use special algorithms to change the active and passive states of sensors.

IV. A SIMPLE DYNAMIC SCHEDULE ACTIVE-PASSIVE NODES ALGORITHM

One of the main objectives in WSNs is to increase the lifetime of the network. Unlike traditional WSNs, where such increase is usually based on the selection of the appropriate routing algorithm [14, 15], in the case of Sensor Web network there is a need for a different solution. As it already stated, Sensor Web is traditionally defined as a web of interconnected heterogeneous sensors that are interoperable, intelligent, dynamic, scalable and flexible, but can often be presented as a group of interoperable web services which all comply with a specific set of behaviors and sensor interfaces specifications [2], where the difference between ordinary sensor and Sensor Web to the end user shouldn't be visible [17].

In the case considered in this work, a sensor node that can have two states is created, unlike traditional sensor nodes that were mentioned earlier, which usually have four states (Transmit, Receive, Idle and Sleep). Thus, two states that a sensor node can have are:

- active – all units are active (Fig. 8),
- passive – only transceiver unit is active (a condition in which a sensor node maintains the minimum activities necessary to wake up a sensor).

In both conditions, the sensor node can communicate with the central unit, which is responsible for monitoring and controlling sensor networks.

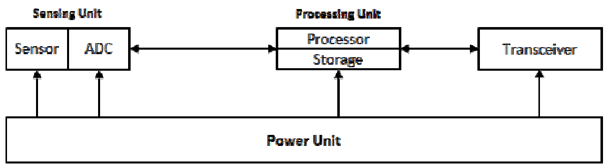


Figure 8. Typical sensor node architecture

The main principle of saving energy and increasing Sensor Web network lifetime can be based on scheduling [13] or on the Smart Sleep [18] approach. In both cases, the solution is primarily based on the planning and setting up of a number of sensor nodes in an active and passive state. What is most important when applying this method is to determine the proper network settings, i.e., define the following goals:

- The minimum number of active sensors (but the sensor network performance shouldn't be significantly disrupted);
- Distance between the sensor vs. sensors' power;
- Time changes between active/passive states of nodes;
- Algorithm for controlling the active/passive sensor nodes;
- The actions taken at the time when the sensor detects a critical event (assuming that the existence of critical points is adopted).

The first two items are directly related to the topology of the sensor network and the area where the sensor network is deployed. Identification of these elements is usually done using a complex mathematical simulation or empirical methods.

As the proposed Sensor Web network can be managed centrally and dynamically, switching between the active/passive nodes states can be determined depending on the situation. It is important to note that as the frequency of switching increases, the accuracy of the sensor network grows up, and approaches the situation shown in Fig. 2. Consequently the energy saving in this case decreases.

The algorithm for controlling the active/passive sensor nodes performs on complete set of sensor network nodes divided into two groups: active sensor nodes and passive sensor nodes and all their adjacent nodes (in the hexagonal network for every node there are maximal three adjacent nodes) - Fig. 9.

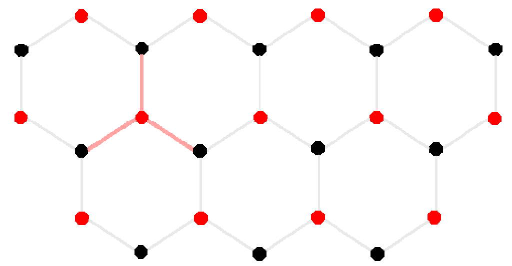


Figure 9. Hexagonal Sensor Web deployment: Non alert state
Red dot – active sensor, *Black dot* – passive sensor, *red line* – adjacent sensors

In Fig. 9 red nodes are active nodes while the black ones are passive. Connections between the nodes are shown only for a better understanding of adjacent nodes (red marked connections are connections between adjacent nodes), although they do not exist in the real system.

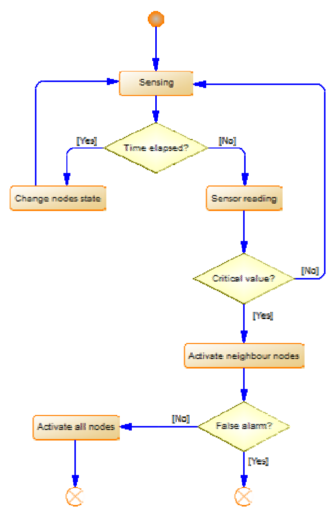


Figure 10. The activity diagram of hexagonal Sensor Web network

The algorithm works by a combination of scheduling and smart sleep algorithm. In a given time interval, only one group of sensors is active, while the second group is in the passive state. After the time interval elapses, states of active and passive sensors are changed. The activity diagram of proposed algorithm is presented in Fig. 10. It is obvious that, upon the detection of critical event in the network, it is necessary to activate all the neighbouring nodes immediately (adjacent nodes that are not active – Fig. 9). Fig. 11 depicts the state of adjacent sensor network nodes upon activation.

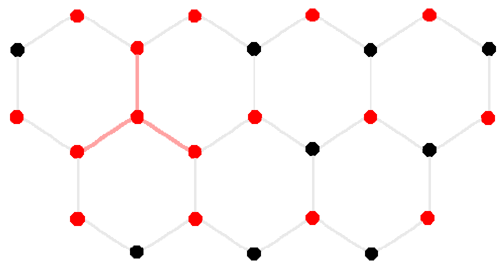


Figure 11. Hexagonal Sensor Web deployment: Alert state

In the case that one of sensors has been activated by smoke presence, the adjacent sensors should be awaked immediately to avoid possibility of false alarm existence. If at least one of those sensors also detects a presence of smoke whole sensor network should become active. In this way, the entire sensor network is active only during a detection of critical event, while in other cases the maximum number of active nodes is (n/2) +3 (n is total number of sensors in network) which represents a saving of 25-50%, depending on the size of the sensor network.

V. Simulation Results

The aim of simulations performed using Pyrosim software tool [19] is to make a comparative analysis between proposed deployment schemes and to realize influence of number of active sensors and each of proposed schemes to detection of fire and network lifetime in a presence of fire. As long as one sensor is alive there is a possibility that information about the location and spread of the fire will be provided to higher level.

For the simulation purposes five different positions of fire ignition are considered (Fig. 12).

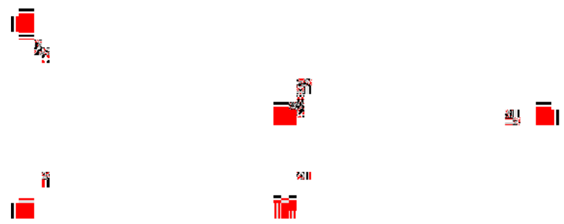
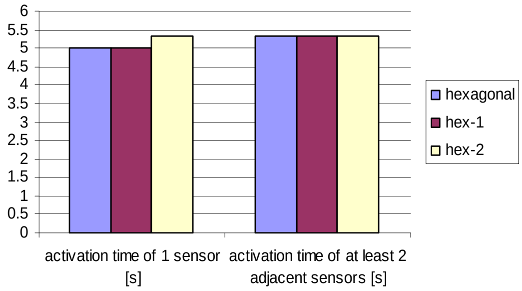
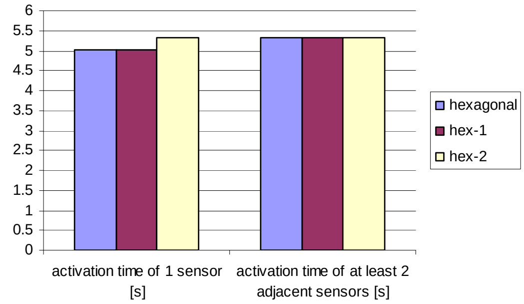


Figure 12. Fire source positions (size 2 x 2 m)

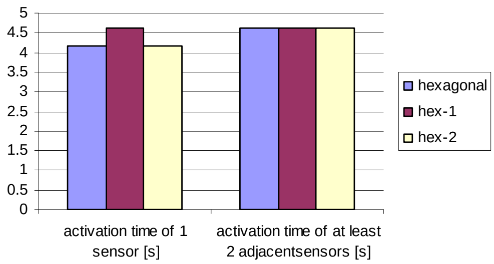
During the simulation process it is assumed that in first case all 18 sensors are active while in other two cases only 9 sensors are active in presence of fire, according to Fig. 4 and 6. Simulation results are given in Fig. 13.



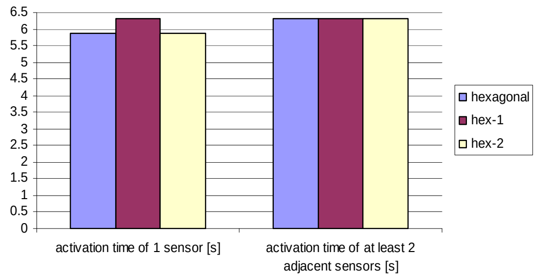
(a) fire source position “1”



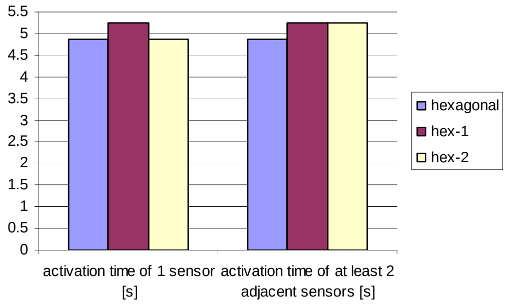
(b) fire source position “2”



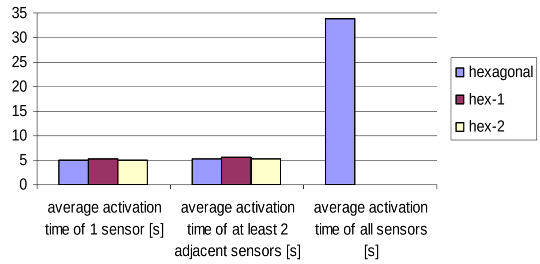
(c) fire source position “3”



(d) fire source position “4”



(e) fire source position “5”



(f) Average activation time

Figure 13. Response sensor times for five proposed fire source positions and average activation time in a case of three proposed deployment strategies

Fig. 13 (a)-(e) show that for fire source positions “1”-“5” there is no significant difference between initial deployment of 18 sensors and hex-1 and hex-2 deployments where are only 9 sensors active. The faster reaction time can be measured in tens of seconds, but in the event of a fast moving fire, these are precious seconds. According to results presented in Fig. 13 (a)-(e) and average values of activation times for all observed cases shown in Fig. 13 (f), it can be noted that the maximum delay in activation times of hex-1 and hex-2 model compared to initial deployment scheme is 0.5 s.

VI. Conclusion

Choice of deployment strategy, being the first step in forming any WSN, depends on applications, requirements and design goals. WSN application in fire detection requires accurate deployment of the sensors and long network lifetime. A hexagonal grid-based deployment on which bases all known optimal patterns can be generated, is considered in this paper. The network lifetime is increased by the proposed solution which is consisted in rotating of hex-1 and hex-2 schemes in certain time intervals. Thus, instead of all 18 active sensors, periodically it will be active one of schemes: hex-1 or hex-2, what means that during the whole monitoring time only 9 sensors will be active always. That should lead to significant reduce of energy consumption and overall longest network lifetime. Simulation results have shown that, by only 9 active sensors, fire will be detected accurately and on time. In the case that one of sensors has been activated by smoke presence, the adjacent sensors should be awakening immediately to solve problem of false alarms existence. If any of those sensors also detect a presence of smoke whole network consisted of 18 sensors should become active in order to obtain as much information about fire as possible. Advantage of the Sensor Web is that it provides a mechanism for authorized professionals to access sensed data remotely using Internet connection. In the case of fire is detection, the fire department will be provided with a constant stream of information about the location and spread of the fire while the deployed firefighters will have information about building plan, an initial location of the fire, its spread, development of smoke, presence of toxic gases and other factors which may affect them.

Improvement of proposed scheduling algorithm and optimization of transceiver unit energy consumption will be the main aim of our future research.

REFERENCES

[1] L. Atzori et al., "The Internet of Things: A survey," *Computer Networks*, pp. 2787-2805, October 2010.

[2] D. Liping, "Geospatial Sensor Web and Self - adaptive Earth Predictive Systems (SEPS)," Proceedings of the Earth Science Technology Office (ESTO)/Advanced Information System Technology (AIST) Sensor Web Principal Investigator (PI) Meeting, San Diego, USA, 2007

[3] M. Rouached, S. Baccar, M. Abid, "RESTful SensorWeb Enablement Services for Wireless Sensor Networks," 2012 IEEE Eighth World Congress on Services, pp. 65-72

[4] R. Ramadan and H. El-Rewini, H, "Deployment of Sensing Devices: A Survey," [Online]. Available:
http://rabieramadan.org/papers/deployment%20survey.pdf

[5] H. Zhang and J.C. Hou, "Is Deterministic Deployment Worse than Random Deployment for Wireless Sensor Networks?" 25th IEEE International Conference on Computer Communications *INFOCOM 2006.*

[6] N. Hadžiefendić, "Detekcija požara", Beograd, 2006 [Online]. Available:
http://spec-nstalacije.etf.rs/predavan/glava_5/DojavaPozara.pdf

[7] M. Cardei and J. Wu, "Coverage in wireless sensor networks," in *Handbook of Sensor Networks*, M. Ilyas and I. Magboub, Eds. USA: CRC Press, pp. 19.1-19.10. 2004

[8] C.T. Vu, "An Energy-Efficient Distributed Algorithm for k-Coverage Problem in Wireless Sensor Networks" *Computer Science Theses.* Paper 40, 2007

[9] K. Kar and S. Banerjee, "Node placement for connected coverage in sensor networks," in the Proceedings of the Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt'03), Sophia Antipolis, France, 2003

[10] Z. Cheng, M. Perillo, W. Heinzelman, "General network lifetime and cost models for evaluating sensor network deployment strategies," *IEEE Transaction on Mobile Compuing.* 2008, 7, 484–497.

[11] Y. E. Aslan, "A Framework for the use of Wireless Sensor Networks in forest fire detection and monitoring," , Master thesis, The Institute of Engineering and Science of Bilkent University, 2010.

[12] Z. Yun, X. Bai, D. Xuan, T. H. Lai, and W. Jia, "Optimal Deployment Patterns for Full Coverage and k-Connectivity ($k \leq 6$) Wireless Sensor Networks," *IEEE/ACM Transactions on Networking*, vol. 18, no. 3, 2010

[13] R. Rathna, A. Sivasubramanian, "Improving Energy Efficiency in Wireless Sensor Networks through scheduling and routing," *International Journal Of Advanced Smart Sensor Network Systems (IJASSN),* Vol. 2, No.1, 2012

[14] A. Salhieh, J. Weinmann, M. Kochhal, and L. Schwiebert. "Power Efficient Topologies for Wireless Sensor Networks," In Proc. of Intl. Conf. on Parallel Processing (ICPP), 2001.

[15] K. D. Hanabaratti, R. Jogdand, "Design of an Efficient Random Walk Routing Protocol for Wireless Sensor Networks," *IJECT* Vol. 2, Issue 4, 2011

[16] U. Aeron, H. Kumar, "Coverage Analysis of Various Wireless Sensor Network Deployment Strategies," *International Journal of Modern Engineering Research (IJMER)* Vol.3, Issue.2, March-April. 2013 pp-955-961

[17] K. A. Delin, "Sensor Webs in the Wild", *Wireless Sensor Networks: A Systems Perspective*, Artech House, 2005

[18] C. H. Lee, D. Y. Eun, "Smart sleep: Sleep more to reduce delay in duty-cycled wireless sensor networks," INFOCOM 2011: 611-615

[19] Pyrosim software tool, [Online]. Available:
http://www.thunderheadeng.com/pyrosim/