Maximization of Lifetime Schedule for WSN in Structural Health Monitoring

R Tamilselvan[1] P.Madhubala[2] Dr.K.Murugesan[3]
[12]II M.E, CSE , [3]AP, CSE Professor,
Tagore Institute of Engineering Tagore Institute of Engineering SMK Fomra Institute of
and Technology, and Technology, Technology, Chennai. India.
Deviyakurichi, Attur Deviyakurichi,
Salem,India. Salem,India

---***---

Abstract *— To develop a mathematical model and formulate the problem as a large-scale mixed integer non-linear programming problem. To propose a solution based on the Enhanced Branch-and-Bound algorithm augmented with reducing the search space. The proposed strategy builds up the optimal route from each source to the sink node by providing the best set of hops in each route and the optimal power allocation of each sensor node. To reduce the computational complexity, we propose heuristic routing algorithms. In this heuristic algorithm, the power levels are selected from the optimal predefined values, the problem is formulated by an integer non-linear programming, and the Branch-and-Bound reduced space algorithm is used to solve the problem. We propose two sub-optimal algorithms to reduce the computation complexity. In the first algorithm, after selecting the optimal transmission power levels from a predefined value, a genetic algorithm is used to solve the integer non-linear problem. In the second sub-optimal algorithm, we solve the problem by decoupling the optimal power allocation scheme from the optimal route selection. Therefore, the problem is formulated by an integer non-linear programming, which is solved using the Branch-and-Bound space-reduced method with reduced binary variables (i.e., reduced complexity), and after the optimum route selection, the optimal power is allocated for each node. The numerical results reveal that the presented algorithm can prolong the network lifetime significantly compared with the existing schemes. Moreover, we mathematically formulate the adaptive energy harvesting period to increase the network lifetime with the possibility to approach infinity.*

Index Terms—WSN, MEMS, Structural health Monitoring, Energy lifetime

1. INTRODUCTION

The new advances in sensor device technologies make wireless sensor networks (WSNs) more effective and economically-viable solutions for a wide variety of applications, such as environmental monitoring, scientific exploration, and target tracking. Structural health monitoring (SHM) systems are implemented for civil structures (including buildings, bridges, tunnels, aircraft, among others) to monitor their operations and health status. The monitoring of civil structures enables damage prediction and therefore, repairs anticipation thus avoiding accidents. WSNs are becoming an enabling technology for SHM that are more prevalent and more easily employable than current wired systems. Traditionally, a sensor node is mainly powered by a non rechargeable battery, which has a limited energy storage capacity. As a result, a WSN can only function for a limited amount of time. A lot of research efforts have been dedicated to prolong the lifetime of a WSN by improving its energy efficiency. There are a number of studies on energy harvesting, recharging and their implications in WSN. Akhtar and Rehmani [5] focus on energy harvesting from renewable as well as traditional energy resources in sustainable WSNs. In this paper the available sources for different applications of WSNs, techniques used for scavenging, storage methods and deployment architecture are discussed.

Currently, the main sources of ambient energy that are considered suitable for use with WSNs are solar, thermal energy, and mechanical (vibration or strain). Solar power is the most common and matured among the different forms of energy harvesting. However, it has the drawback of being able to generate energy only when there is sufficient sunlight or artificial light. Thermal energy harvesting uses temperature differences or gradients to generate electricity, e.g. between the human body and the surrounding environment. Thermal energy harvesting systems are easy to integrate with micro devices; however, their use is limited to space and terrestrial applications. Vibration, dynamic and mechanical energy generated by movements of objects can also be harvested. Vibrations are present all around us and especially prominent in bridges, roads and rail tracks. The methods of harvesting vibration energy is through the use of a electrostatic generator , piezoelectric capacitor , or micro electromagnetic generator Advantage of electrostatic harvesting devices is ease of integration and no need for smart materials and the output voltage is high. However, electrostatic devices are highly dependent on the external voltage source. Piezoelectric energy harvesters require no external voltage source and the output voltage is relatively high. However, piezoelectric materials, such as PZT, are often brittle and their material properties change through operational life. Electromagnetic generators are simple and rugged, but are difficult to manufacture in micro scale.

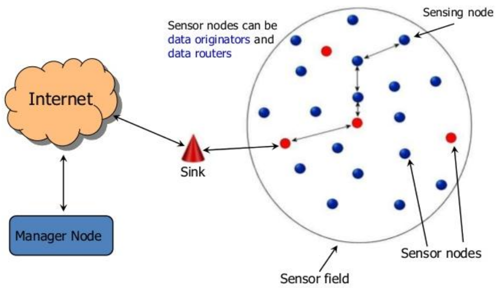

Fig.1.WSN communication Architecture

At first Wireless Sensor Network (WSN) was developed for military Applications [1], In WSN, sensors are very powerful, smaller and less expensive, therefore, its use expanded in civilian applications. The sensors used in WSN are advantageous in friendly as well as in harsh conditions without any power and communication lines to periodically sense and transmit data to the sink, hence it is widely used. In present-time, a wide range of civilian applications such as habitat, environment and health monitoring [2] have been deployed. Currently the issue of power consumption is very important in sensor development. Transceiver is an important constituent of sensor node that operates at a specific frequency for data communication which is sensitive to several environmental conditions. As it has already mentioned that sensor nodes which are used in WSNs are usually battery powered but nodes are typically unattended because of their deployment in hazardous, hostile or remote environment.

A general centralized IWSN scenario is depicted in with nodes, sink/network manager, management console, and process controllers. The nodes collect data and communicate it the sink/network manager which in turn communicates this data to the process controller. The nodes are managed by the network manager and the network manager can be controlled via a management console. The black arrows show a path through which a sensor node at the far end communicates to the sink via other nodes.

I. LITERATURE SURVEY

In this section, the sensor placement is the main issue for monitoring. Here various authors have been proposed the different methodologies for the wireless sensor placement issue in structural health monitoring. In WSN consists of a network of nodes and data is communicated between two nodes e.g. between a source and a sink. These are usually multi-hop networks where each sensor node needs to send data. Thus we have multiple nodes attempting to send data via intermediate nodes creating traffic that requires efficient management to satisfy the IWSN QoS requirements.

A. Health Monitoring of Civil Structure using Wireless Sensor

In this study[4] increased knowingness of the economic and social effects of aging of the structure, deterioration and extreme events on civil infrastructure has been coupled by recognition of the need for advanced structural health monitoring and damage detection tools. Structural health monitoring techniques depends on changes in dynamic characteristics have been studied for the past three decades. When the damage is significant, these methods have some success in determining if damage has occurred. Most global health monitoring methods are centered on either finding shifts in resonant frequencies or changes in structural mode shapes. Early health monitoring found that loss of a single shape in a structure can result in changes in the fundamental natural frequency. Next level of sophistication of health monitoring approaches proposes to find the location of cracks based on the natural frequency drift. Most of these methods stipulate that the only form of damage is cracking, and by extension loss of cross sectional areas. These assumptions limit the method to some very special situations. These new sensors include Micro-electromechanical System (MEMS) devices for accelerometers and other application, nuclear magnetic resonance (NMR) encapsulates to detect chloride ions. LIDAR to capture 3D position of objects.

B. High Quality Sensor Placement for SHM Systems

Refocusing on Application Demands It focuses on the sensor placement on the civil requirements and on the computer science requirements [6]. It provides the placement quality of the candidate locations of the sensors in step by step manner. Then optimize the system performance, by considering networking connectivity and data routing issues; with the objective on energy efficiency. For this, this process leads to the introduction of the new method called Sensor Placement using EFI method (SPEM). The deployment of the sensors must be in EFI method and not be in regular forms (i.e.) grids or tree form. The Effective Independence placement method gives the appropriate location of the sensors. It shows the topology control, data routing and energy efficiency which can be integrated with the SHM framework. But it have some disadvantages, is that the computer requirements constraints should be adjusted with the civil placement quality constraints which leads to missing of some optimal locations in the structure. It also fails to recover from fault in wireless sensors while monitoring.

C. Relay Node Deployment Strategies in Heterogeneous Wireless Sensor Networks

It focuses on the sensor deployment issue in WSNs. The number and positions of sensors determine the usability of a sensor node in terms of coverage, connectivity, lifetime, cost, etc. Here, the impacts of random device deployment on connectivity and lifetime in a large-scale heterogeneous WSN. The deployment of the RNs can have a significant impact on connectivity and lifetime of a WSN system[7]. The former solely aims at balancing the energy consumption rates of RNs across the network, thus prolonging the system lifetime. The RNs which are away from the BS will dissipate energy speeder than the RNs closer to the BS due to the larger transmission distance. As such, the nodes are away from the BS become unusable, while a large part of energy is still left on those close to the BS.

Routing protocols are used for efficient routing of the data through the network. Over the years, various routing protocols have been proposed to satisfy the QoS requirements [14]. We discuss the most relevant protocols and also the main design requirements for an efficient routing protocol. There are many design requirements that can be used to select a routing protocol. We focus on requirements relevant to the IWSN classes of systems as defined in this article. Detailed information on various routing metrics e.g., average path length, that have to be considered during design of routing protocols has been provided by Khan and for industrial routing requirements. The routing metrics have two use cases; firstly they can be used to evaluate a proposed routing protocol by describing the performance in terms of the metrics, secondly the routing metrics are used by the routing protocols to construct efficient routes dynamically. The requirements also partly include network layer functionalities implemented to forward packets that affect the routing decisions made. Packet scheduling and packet priority are two requirements involved in the packet forwarding process.

II. STANDARDIZATION ACTIVITIES

In this section, major standardization efforts related to IWSNs are briefly described.

A. ZigBee

ZigBee is a mesh-networking standard based on IEEE 802.15.4 radio technology targeted at industrial control and monitoring, building and home automation, embedded sensing, and energy system automation. ZigBee is promoted by a large consortium of industry players. The good characteristics of the ZigBee are extremely low energy consumption and support for several different topologies, which makes it a good candidate Authorized licensed use limited to for several sensor network applications. it is reported that ZigBee cannot meet all the requirements for at least some industrial applications[11]. For example, it cannot serve the high number of nodes within the specified cycle time.

B. Wireless HART

Wireless HART is an extension of the HART protocol and is specifically designed for process monitoring and control. Wireless HART was added to the overall HART protocol suite as part of the HART 7 Specification, which was approved by the HART Communication Foundation. The technology employs IEEE 802.15.4-based radio, frequency hopping, redundant data paths, and retries mechanisms. Wireless HART networks utilize mesh networking, in which each device is able to transmit its own data as well as relay information from other devices in the network [10].

C. UWB

Ultra wideband (UWB) is a short-range wireless communication technology based on transmission of very short impulses emitted in periodic sequences [8]. The initial applications of UWB include multimedia and personal area networking. Recently, UWB-based industrial applications have gained attention [9].

On the other hand, UWB is not a viable approach for communication over longer distances or measuring data from unsafe zone because of high peak energy of pulses. The advantages of UWB are good localization capabilities, possibility to share previously allocated radio-frequency bands by hiding signals under noise floor, ability to transmit high data rates with low power, good security characteristics due to the unique mode of operation, and ability to cope with multipath environments. The wireless sensor network lifetime definition varies depending on the specific application, on the objective function and on the network topology considered and it can be defined as follows: (1) the time instant at which a certain number of nodes in the network depleted their batteries (2) the lifetime of the specific sensor node associated with the highest energy consumption rate, (3) the instant, when the first data collection failure occurred , and (4) the duration of time before the first node in the network was depleted (or become unavailable) .

In this paper, assuming the latest definition for the network lifetime, we propose a framework to maximize network lifetime with and without energy harvesting.

Lifetime maximization in WSNs is a well studied topic, however, to the best of our knowledge, there is no analytical model which can accurately formulate optimum routing to maximize lifetime of energy harvesting WSN for structural health monitoring.

III. PROPOSED SOLUTION

The Branch-and-Bound algorithm is by far the most widely used tool for solving integer optimization problems. Obviously, the optimal value of the objective function in a continuous linear relaxation of a problem will always be a lower bound on the optimal value of the objective function. Moreover, in any minimization, any feasible point always specifies an upper bound on the optimal objective function value. The idea of the Branch-and-Bound is to utilize these observations to subdivide MINLP's feasible region into more-manageable subdivisions and then, if required, to further partition the subdivisions.

These subdivisions make a so called enumeration tree whose branches can be pruned in a systematic search for the global optimum. Optimal solution using branch-and-bound space reduced pseudo code.

A. Enhanced Branch-And-Bound Space Reduce Algorithm(EBBSRA)

We enhance the Branch-and-Bound algorithm and develop a Branch-and-Bound Space Reduced algorithm to solve the MINLP [1]. This proposed algorithm reduces the Branch and-Bound area of a search and implements the Branch-and Bound relaxation and separation strategy to solve the problem. Since any feasible solution of problem ω can serve as an upper bound, the one obtained by rounding under the satisfaction of all constraints is used and denoted as BU.

Branch and bound is an algorithm design paradigm for discrete and combinatorial optimization problems, as well as mathematical optimization. A branch-and-bound algorithm consists of a systematic enumeration of candidate solutions by means of state space search: the set of candidate solutions is thought of as forming a rooted tree with the full set at the root. The algorithm explores branches of this tree, which represent subsets of the solution set. Before enumerating the candidate solutions of a branch, the branch is checked against upper and lower estimated bounds on the optimal solution, and is discarded if it cannot produce a better solution than the best one found so far by the algorithm [12].

The goal of an enhanced branch-and-bound algorithm is to find a value x that maximizes or minimizes the value of a real-valued function f(x), called an objective function, among some set S of admissible, or candidate solutions. The set S is called the search space, or feasible region. The rest of this section assumes that minimization of f(x) is desired; this assumption comes without loss of generality, since one can find the maximum value of f(x) by finding the minimum of g(x) = −f(x). A B&B algorithm operates according to two principles:

- It recursively splits the search space into smaller spaces and then minimizing f(x) on these smaller spaces; the splitting is called branching.
- Branching alone would amount to brute-force enumeration of candidate solutions and testing them all. To improve on the performance of brute-force search, a B&B algorithm keeps track of bounds on the minimum that it is trying to find, and uses these bounds to "prune" the search space, eliminating candidate solutions that it can prove will not contain an optimal solution.

Turning these principles into a concrete algorithm for a specific optimization problem requires some kind of data structure that represents sets of candidate solutions. Such a representation is called an instance of the problem. Denote the set of candidate solutions of an instance I by SI. The instance representation has to come with three operations:

- Branch (I) produces two or more instances that each represent a subset of SI. (Typically, the subsets are disjoint to prevent the algorithm from visiting the same candidate solution twice, but this is not required. The only requirement for a correct EB&B algorithm is that the optimal solution among SI is contained in at least one of the subsets.
- Bound(I) computes a lower bound on the value of any candidate solution in the space represented by I, that is, bound(I) ≤ f(x) for all x in SI.
- Solution (I) determines whether I represents a single candidate solution. (Optionally, if it does not, the operation may choose to return some feasible solution from among SI.

B. HEURISTIC ENERGY HARVESTING LIFETIME MAXIMIZATION ROUTING

We propose a heuristic routing algorithm which, at first obtains optimal power levels of all connection links and then solves the routing problem. Employing the power levels turns the problem to Integer Programming problem that can be solved using EBnB Space Reduced algorithm [1].

Table 1. Heuristic Energy Harvesting Lifetime Maximization Algorithm.

Input: A predetermined located set of nodes, $\mathbb{N}$,
A set of source nodes, $\mathbb{S}$, and a destination node, D;
1: $\mathbf{P^t} \leftarrow \mathbf{P^{top}}$, ;
2: $E_T^{\text{net\_C\_prim}} = \{E_T^{\text{net\_C}} |_{\mathbf{P^t}=\mathbf{P^{top}}}\}$;
3: solve the integer problem using BnB space reduce Algorithm in Table I and denote its results as E_T^*;
4: optimal power allocation for E_T^*;
5: obtain optimal power allocation for each transmitter
6: **Output** Optimal path with optimal power allocation.

To obtain the optimal power allocation, the signal-to-noise ratio (SNR) must be greater than or equal to the detection threshold (β). Therefore, the optimal power that minimizes energy consumption for the transmission from node *i* to node *j* is given by,

$$P_i^{top} = \frac{\beta N_o r_{i,j}^{\gamma}}{\epsilon_{amp}}, \quad (1)$$

Where *No* is the noise power. The proposed heuristic routing algorithm is presented in Table 1. The calculated power level is employed in BnB and therefore, the complexity of the algorithm is reduced due to elimination of the non-integer variables in the optimization problem.

C. POWER DISJOINT ENERGY HARVESTING LIFETIME MAXIMIZATION

In order to reduce the computational complexity caused by obtaining optimal power levels of all potential connection links, we propose a new algorithm in which the optimal transmission power is allocated after the routing solution [3]. Energy harvesting can be possible through ambient power sources such as solar, thermal, mechanical radio frequency etc. A very interesting fact of harvesting energy is that, the joint venture of harvesting source's random nature and communication process results the temporary depletion of energy storage unit of sensor nodes. Some research works find good solution, by using piezoelectric materials for conversion of strain energy from a structure into electrical energy to harvest energy to the sensor nodes in the network [13].

Table 2. Powers disjoint energy harvesting lifetime maximization.

Input: A predetermined located set of nodes, $\mathbb{N}$,
A set of source nodes, $\mathbb{S}$, and a destination node, D;
1: $\mathbf{P^t} \leftarrow P_f^t$ dBm, ;
2: $E_T^{\text{net\_C\_prim}} = \{E_T^{\text{net\_C}} |_{\mathbf{P^t}=P_f^t}\}$;
3: solve the relaxed problem using BnB space reduce Algorithm in Table I and denote its results as E_T^*;
4: optimal power allocation for E_T^*;
5: obtain optimal power allocation for each transmitter
6: **Output** Optimal path with optimal power allocation.

The proposed sub-optimal lifetime maximization algorithm is presented in Table 2. This algorithm uses equal, fixed transmission power, $P^t{}_f$, in the objective function and the constraints. Therefore, the problem is simplified to an Integer Programming Problem. The BnB Space Reduced algorithm is employed to solve the problem as well (line 3). After optimal path selection using BnB Space Reduced algorithm, the optimal power allocation is allocated to each hop.

IV. RESULTS AND PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed Algorithms. We consider predetermined node locations con- sisting of 9 sensor nodes in 9 floor building.

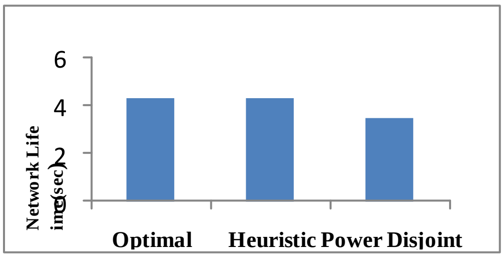

Fig.2. Comparing the routing obtained from optimal solution

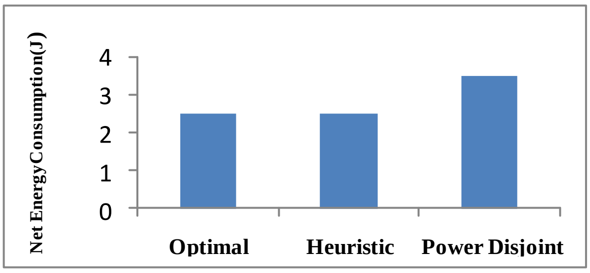

Fig.3. Comparing network lifetime of optimal solution

Network lifetime and net energy consumption of the optimal routing solution using EBnB space reduced algorithm and that of the heuristic algorithm; sub-optimal solutions are compared in Fig. 2 and Fig.3 respectively.

It is evident that routing solution using BnB space reduced solution performance is similar to that of the heuristic algorithm. The reason of the equal performance for the heuristic algorithm and optimal solution is that the heuristic method is obtaining the same optimal power level allocation as the optimal solution and it solves the problem employing the same method with a lower complexity [15]. The results show that routing using the BnB solution and the heuristic algorithm outperform the other routing algorithm and the lifetime of routing using BnB solution and the heuristic algorithm increased by 11% compared to sub-optimal lifetime maximization.

VI. CONCLUSION

In this paper, we presented the optimal solution to maximize the lifetime of wireless sensor network for structural health monitoring system by joint use of optimal power and route selection with and without energy harvesting. This optimization problem is inherently complex due to its mixed integer nature, non-linearity, and a large solution space. We developed an efficient solution procedure based on the Enhanced Branch-and-Bound technique augmented with a space reduction algorithm to speed up the computation. Then, we proposed the heuristic routing algorithm to reduce the computational complexity by decoupling transmission power allocation in the routing algorithm from the optimal route selection. Results reveal that the heuristic routing algorithm performs similar to the optimal routing using Branch-and-Bound space reduced algorithm.

The performance of the proposed routing algorithms is compared with existing algorithms and the results demonstrate the significant gains that can be achieved by incorporating energy harvesting and power allocation in route selection for maximizing the lifetime of wireless sensor networks. Moreover, we presented the adaptive energy harvesting period and the infinite lifetime achieved using the minimum energy harvesting period. There are several directions for future work, including development of a dynamic routing algorithm that establish rerouting automatically as soon as the critical node depletes to a predefined remaining energy.

REFERENCES

[1] F.Mansourkiaie, Loay Sabry Ismail, ,Tarek Mohamed Elfouly And Mohamed H. Ahmed , "Maximizing Lifetime in Wireless Sensor Network for Structural Health Monitoring With and Without Energy Harvesting", Special Section On Energy Harvesting And Scavenging: Technologies, Algorithms, And Communication Protocols in IEEE Access,vol.5,2017.

[2] A. Ajith Kumar S., K. Ovsthus, and L. M. Kristensen, "An industrial perspective on wireless sensor networks—A survey of requirements, protocols, and challenges," IEEE Commun. Surveys Tuts., vol. 16, no. 3, pp. 1391–1412, 3rd Quart., 2014. [2] F. A. Silva, "Industrial wireless sensor networks: Applications, protocols, and standards [book news]," IEEE Ind. Electron. Mag., vol. 8, no. 4, pp. 67–68, Dec. 2014.

[3] M. Elsersy, T. M. Elfouly, and M. H. Ahmed, "Joint optimal placement, routing, and flow assignment in wireless sensor networks for structural health monitoring," IEEE Sensors J., vol. 16, no. 12, pp. 5095–5106, Jun. 2016. VOLUME 5, 2017 2393 F. Mansourkiaie et al.: Maximizing Lifetime in Wireless Sensor Network for Structural Health Monitoring.

[4] P. Cheng, C. N. Chuah, and X. Liu, "Energy-aware node placement in wireless sensor network," in Proc. Global Telecommun. Conf. (GLOBECOM), 2004, pp. 3210–3214.

[5] F. Akhtar and M. H. Rehmani, "Energy replenishment using renewable and traditional energy resources for sustainable wireless sensor networks: A review," Renew. Sustain. Energy Rev., vol. 45, pp. 769–784, May 2014.

[6] Heo G, Wang ML, Satpathi D. "Optimal transducer placement for health monitoring of long span bridge". Soil Dynamics and earthquake Engineering 1997;16:495–502.

[7] W. B. Heinzelman, A. P. Chandrakasan, H. alakrishnan, "An Application-Specific Protocol Architecture for Wireless Micro sensor Networks", IEEE Transactions On Wireless Communications, 1(4):660-670, 2002.

[8] H. Salarian, K.-W. Chin, and F. Naghdy, "An energy-efficient mobile-sink path selection strategy for wireless sensor networks," IEEE Trans. Veh. Technol., vol. 63, no. 5, pp. 2407–2419, Jun. 2014.

[9] Y. Chen and Q. Zhao, "On the lifetime of wireless sensor networks," IEEE Commun. Lett., vol. 9, no. 11, pp. 976–978, Nov. 2005.

[10] J. W. Jung and M. A. Weitnauer, "On using cooperative routing for lifetime optimization of multi-hop wireless sensor networks: Analysis and guidelines," IEEE Trans. Commun., vol. 61, no. 8, pp. 3413–3423, Aug. 2013.

[11] Z. Lu, W. W. Li, and M. Pan, "Maximum lifetime scheduling for target coverage and data collection in wireless sensor networks," IEEE Trans. Veh. Technol., vol. 64, no. 2, pp. 714–727, Feb. 2015.

[12] J. Chen, J. Li, and T. H. Lai, "Trapping mobile targets in wireless sensor networks: An energy-efficient perspective," IEEE Trans. Veh. Technol., vol. 62, no. 7, pp. 3287–3300, Sep. 2013.

[13] M. Najimi, A. Ebrahimzadeh, S. M. H. Andargoli, and A. Fallahi, "Lifetime maximization in cognitive sensor networks based on the node selection," IEEE Sensors J., vol. 14, no. 7, pp. 2376–2383, Jul. 2014.

[14] J. Chen, J. Li, and T. H. Lai, ``Trapping mobile targets in wireless sensor networks: An energy-efficient perspective,'' *IEEE Trans. Veh. Technol.*,vol. 62, no. 7, pp. 3287_3300, Sep. 2013.

[15] M. Najimi, A. Ebrahimzadeh, S. M. H. Andargoli, and A. Fallahi,``Lifetime maximization in cognitive sensor networks based on the node selection,'' *IEEE Sensors J.*, vol. 14, no. 7, pp. 2376_2383,Jul 2014.