Analysis on Energy and Coverage Issues in Wireless Sensor Network

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***Abstract*— Two major fundamental issues in Wireless Sensor Network (WSN) are energy efficiency and coverage. Energy efficiency is the result of controlling and maintaining the energy usage. A method is considered as energy efficient if it can provide more services with the same amount of energy input, while coverage efficiency is measured by how long and how well a sensor monitors the subjected area. Hence, to obtain an energy and coverage efficiency, maximizing the coverage by reducing the energy consumption needs to be achieved. Our paper presents the potential of Derivative Harmon Search Algorithm (DHSA) in a connected WSN to achieve deployment of node that can cover optimal area and at the same time give low energy consumption.**

***Index Terms*— Coverage; Energy Efficiency; Harmony Search Algorithm; Wireless Sensor Network.**

I. INTRODUCTION

The urbanization of Wireless Sensor Networks (WSN) over the years has led researchers to vigorously and continuously conduct studies aiming to achieve high Quality of Service (QoS). Wireless Sensor Networks is a network that consists of numerous numbers of sensor nodes, where each of the sensor nodes is embedded with sensor, which has specific application to detect the environment phenomena, such as temperature, vibration and pressure. WSNs are considered as a part of information gathering method, which has been revolutionized in order to build highly improved and efficient infrastructure systems for the information and communication system [1]. Basically, the sensor nodes are scattering in the WSN area. Once the sensor detects the environment phenomena, it will send the data to the neighbor nodes and pass them to the sink nodes. Sink nodes will then pass the data to the base station (User) via the internet or satellite.

Each of the nodes has the abilities to collect data and route them back to the sink node. The power unit supplies power to the nodes. Sensor nodes are mostly battery powered. Sensing unit enables the nodes to detect the environment phenomena. The data collected will then be transmitted to the neighbor nodes. Communication Unit, which consists of radio, is responsible for this process.

However, WSNs have special characteristics and constraints compared to the cellular system and Mobile ad hoc networking, which is also categorized as the traditional wireless communication [2,3]. Sensor networks are:

- The number of sensor nodes in a sensor network is higher than the nodes in an ad hoc network;
- The nodes are densely deployed in the region of interest to monitor certain events;
- It has limited energy, computational power and storage capacities;
- WSN is considered as self-configurable because no planning is required in deploying the nodes. Once deployed, sensor nodes will automatically configure themselves into a communication network;
- Sensor nodes are prone to failures;
- The topology of the sensor network changes very frequently depending on situation; and
- sensor nodes communicate with other sensor nodes via broadcast communication medium, while most ad hoc networks are based on point-to-point communications.

II. RESEARCH PROBLEM

A. Limited Energy Sources in WSN

One of the limitations of WSN is that it is battery powered; hence, the batteries are impossible to be replaced once they are out since the nodes are densely deployed in the targeted area. A continually unsupervised WSN operation over time, especially in the case of large-scale networks consist of tens to hundreds of nodes, poses the problem of energy autonomy of sensor node. Energy degradation in WSN reduces the QoS, particularly the high end-to-end delay and low throughput. The degradation of QoS causing incomplete message to be received and it becomes worst in emergency cases. Hence, to ensure the WSN application can be operated for a long time, the power consumed by WSN needs to be conserved. The power consumptions of WSN is different depending on its partitions: the sensor, processor, node activities such sending data, receiving data, and the state of the node either it is sleeping or idle. Sending activities consumes the highest energy compared to the other partitions followed by the receiving activities. A node consumes high energy when it is in idle state.

There are two parts that can affect the energy efficiency in each method:

- Device Level – In this level, the selection of components and configuration is made to achieve low energy consumption in WSN.
- Network Level –The communication methods and protocol are chosen wisely to minimize the energy consumption.

For hardware capabilities, three common battery technologies applied in WSN are Alkaline, Lithium and Nickel Metal Hydride.

The types of sensor also affect the consumption of power used in WSN. Table 2 shows the differences in energy consumption between the different types of sensor.

Table 1
Power Consumption of different types of sensor [10]

Sensor	Power Consumption
Gas	500mW-800mW
Image	150mW
Pressure	10mW-15mW
Acceleration	3mW
Temperature	0.5mW-5mW

B. Small range of coverage area due to limited energy sources

Besides energy consumption, another active area of research in WSN is coverage. Coverage problems are due to the limited communication and sensing ranges [11]. Coverage in wireless sensor networks is measured based on how well the sensor monitor the physical space and for how long the sensors are able to last [5]. It is important to understand that the coverage of the network is not equal to the range of the wireless communication links used [9]. Higher number of communication links between the nodes does not mean that the coverage area is larger. In order to solve the problems, the way the sensors are placed with respect to each other must be determined. The main idea of the coverage efficiency is on how to ensure that each of the points in the monitored region is covered by the sensors. To ensure fully utilization of sensing capability of a sensor, the sensors need to be placed not too close to each other However, they must not be located too far from each other to avoid the presence of coverage holes and to ensure the communication between sensors are maintained. The most commonly used computational geometry approaches are Voronoi diagram and Delaunay triangulation. Voronoi diagram encodes the proximity information that helps to answer questions, like "Which object is closest to point p?" Delaunay Triangulation is a triangulation, which is equivalent to the nerve of the cell in Voronoi diagram.

III. Genetic Algorithm

Genetic Algorithm (GA) is a practical, robust optimization and search methods. This method is useful for fields with variation. GA is also known as a global heuristic algorithm that guesses an optimal solution through generating different individuals [16]. GA can be applied to a wide range of constraint satisfaction problems. GA is a technique boosted by natural evaluation to compute and change species to their environment. During each generation, GA technique maintains a population of individuals where each individual is a coded form and is called as chromosome. Each chromosome is evaluated by the fitness function. Next, new population is generated from the present one through selection, crossover and mutation.
The steps of the GA implementations is as follows:

Start: A random population of chromosomes is generated.

Loop: The generation of chromosome population is repeated until termination criteria (generation count) is reached.

Fitness: The fitness and sorting individuals according to the calculated fitness is calculated.

New Population: Crossover and mutation are applied to the current population to form a new population.

Elitism: The best individual is selected and applied to the current sensor deployment.

Solution: The population, which gives the optimal solution.

IV. Harmony Search Algorithm

In 2004, a method called Harmony Search was created by HS Lee in order to overcome the structural engineering problems. Harmony search (HS) algorithm was inspired by the natural musical performance processes that occur when a musician is looking for a better state of harmony, such as during jazz improvisation. In engineering related problems, the solution is determined by an objective function, resembling the musicians seeking to find musically pleasing harmony as determined by an aesthetic [1]. In music improvisation, one harmony vector is created by combining any pitch within the several possibilities, where the combination produces a fine music harmony. If all the pitches make a good solution, that experience is stored in each variable's memory, a better solution can be found by repeating the same Harmony Search steps. In order to test the effectiveness and robustness of the new method, various truss examples with fixed geometries are presented. The method consists of four steps. These steps are:

Step 1= Initialize optimization problem and algorithm parameters.

Step 2 = Initialize Harmony Memory (HM)

$$HarmonyMemory = \begin{bmatrix} x^1 \\ x^2 \\ \vdots \\ x^{HMS} \end{bmatrix} \quad (1)$$

where HMS= solution vector size of HM

Step 3 = Improvise new harmony from HM by making a new harmony vector

$$x' = \left(x_1', x_2', \cdots x_n'\right) \quad (2)$$

based on memory consideration, pitch adjustments. So, it is compulsory to define HMS, HMCR, PAR, and number of searches.

Step 4 = Update HM

Step 5 = Repeat step 3 & 4.

In another work, Improved Harmony Search (IHS) algorithm has been implemented to solve the coverage problem [6]. The method used is the same as the common Harmonic Search, where the newest harmony vector (x') is chosen according to three principles, which are:

1) HM consideration
2) Pitch Adjustment (adjacent value of one value)
3) Random selection

However, the PAR and bandwidth change dynamically with the number of generations and are calculated using the following formulas:

$$PAR = PAR_{\min} + \frac{(PAR_{\max} - PAR_{\min})}{NI - 1} \times (ci - 1) \quad (3)$$

where PAR is the Pitch Adjustment Rate. PAR min stands for minimum pitch adjustment rate and PAR max denotes maximum pitch adjustment rate. NI denotes for the total number of improvisation and CI denotes for the current iteration.

$$BW = BW_{max} e^{\frac{\ln \frac{BW_{min}}{BW_{max}}}{NI} \times (ci - 1)} \quad (4)$$

where BW is the bandwidth for each iteration, BW_{min} is the minimum bandwidth and BW_{max} denotes the maximum bandwidth. However, by using this method, the maximum and minimum for both bandwidth and PAR, which are difficult to deduce and problem dependent need to be determined.

V. Related Works

In [6], k-coverage target sensing field problem was solved with a minimum energy consumption in order to improve leftover energy in a connected WSN. An improvement of HS had been implemented in this method. Improved Harmony Search (IHS) algorithm has been implemented. Harmony Search (HS) is a meta-heuristic algorithm which imitates the improvisation process of a musician to find the perfect state of harmony. MATLAB programming language was used for simulating the coverage and energy efficiency optimization problem.

A similar platform to the platform created by T. Emre Kalayci in [6] was created in order to compare the proposed algorithm, which is IHS. Original HS is also being implemented. Figure 13 shows the result obtained from the simulation. It obviously shows that HIS method gives better performance in terms of the covered area after 2000th generation.

VI. System Design And Implementation

Derivative Harmony Search Algorithm (DHSA) is slightly different compared to the fundamental Harmony Search algorithm, where in order to obtain the new vector, the derivative of the vector will be derived according to the following equation,

$$\frac{\delta f}{\delta_{x_i}} = \frac{1}{K} P_{random} + \frac{n(x_1(k))}{HMS} P_{memory} + \frac{n(x_i(k \mp m))}{HMS} P_{pitch} \quad (5)$$

The derivative harmony search algorithm provides the information that the probability of certain x(k) is being selected. From the equation above, the first term representing the probability of random selection. The second stands for the probability of memory consideration while the third terms stand for the probability of pitch adjustment. Derivative Harmony Search Algorithm is the summation of these three terms. In [7], Geem, Z. W. tried to apply the algorithm on an objective function f (x) = (x-2) + (x-4) to be minimized. From the calculation, the chances to select optimal values increase as the iteration number increases. Hence, the HS algorithm can ultimately find the optimal solution or near-optimal solutions using this stochastic derivative for discrete variables. The stochastic derivatives are also observed in real-world engineering problems, such as water network design.

Table 2
Algorithm DHSA

1. Initialize the harmony search parameters.
   Require: Harmony Memory size (HMS), Pitch Adjusting Rate (PAR), termination criterion, battery level, radius of communication (Rc);
2. Initialize Harmony Memory (HM).
3. Checking the network connectivity between sensor nodes (Depth First Search).
4. Calculating the covered area.
5. Calculating energy consumption.
6. Creating new harmony memory using DHSA

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if covered area of new harmony > existed covered area
    if energy consumption < 10%
       update Harmony Memory (HM)
    else
       new iteration
else
new iteration.
```

The procedure of DHSA is presented in Table 2. The traditional calculus-based derivative provides information of search direction and step size at certain single vector for a function, which has continuous variables while DHSA gives information of probabilistic inclination to select certain discrete point based on multiple vectors stored in HM for a function which has discrete variables.

VII. Conclusion

In this paper, the implementation of Derivative Harmonic Search Algorithm is proposed to extend the coverage area and at the same time reducing the power usage. K-coverage target sensing field problem is solved with minimum energy consumption. The performance of energy consumption is discussed, focusing on extending the coverage area of monitoring. Derivative Harmony Search (DHS) algorithm is an improvement from Harmony Search. Harmony Search (HS) is a meta-heuristic algorithm, which imitates the improvisation process of a musician to find the perfect state of harmony.

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