NODE PLACEMENT OPTIMIZATION USING EXTENDED VIRTUAL FORCE AND CUCKOO SEARCH ALGORITHM IN WIRELESS SENSOR NETWORK

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Abstrak

Penempatan nod adalah salah satu daripada isu asas yang mempengaruhi prestasi kawasan liputan dan sambungan penderia tanpa wayar (WSN). Dalam WSN berskala besar, nod penderia disebarkan secara rawak di mana beberapa nod penderia adalah berselerakan terlalu rapat dan jauh dari satu sama lain. Penempatan rawak ini menyebabkan beberapa isu seperti lubang liputan, pertindihan dan kegagalan sambungan di mana ia yang menyumbang kepada prestasi kawasan liputan dan sambungan WSN. Model penempatan nod dibina untuk mencari penempatan nod yang optimum dan mengekalkan kawasan liputan serta menjamin penyambungan di dalam penempatan rawak. Prestasi Algoritma Perlanjutan Tolakan Maya (EVFA) dan algoritma Carian Cuckoo (CS) dinilai dari segi liputan dan sambungan. EVFA menunjukkan peningkatan kawasan liputan dan sambungan adalah terjamin berbanding dengan algoritma CS. Kedua-dua algoritma ini mempunyai kelebihan tersendiri dalam meningkatkan prestasi liputan selepas pelancaran rawak awal. Pendekatan EVFA boleh menyusun semula nod penderia menggunakan daya tolakan dan tarikan selepas pelancaran rawak awal dan algoritma CS adalah lebih cekap dalam meneroka carian kawasan liputan maksimum dalam penempatan rawak. Kajian ini mencadangkan algoritma Perlanjutan Tolakan Maya dan Carian Cuckoo (EVFCS) hasil gabungan antara algoritma EVFA dan CS untuk teknik penempatan nod dalam pencarian penempatan nod yang optimum. Ia bertujuan untuk meningkatkan liputan rangkaian dan hubungan dengan minimumkan lubang liputan dan kawasan bertindih. Satu siri kajian eksperimen kepada penilaian algoritma telah dijalankan dalam persekitaran simulasi. Dalam EVFCS, algoritma ini digunakan untuk mencari nilai jarak ambangan yang terbaik dan menggunakan nilai tersebut untuk menyusun semula kedudukan terbaru nod. Hasil kajian menunjukkan bahawa 18.212m adalah nilai jarak ambang terbaik yang mampu memaksimumkan kawasan liputan. Ia juga dapat mengurangkan masalah lubang liputan dan pertindihan serta menjamin kualiti sambungan. Ini membuktikan bahawa EVFCS mengatasi pendekatan EVFA dan mencapai peningkatan yang signifikan dalam kawasan liputan dan menjamin penyambungan. Perlaksanaan algoritma EVFCS dapat memperbaiki masalah yang dihadapi selepas penempatan rawak awal.

Kata kunci : Rangkaian penderia tanpa wayar, Lubang liputan, Pertindihan kawasan, Algoritma Perlanjutan Tolakan Maya dan Carian Cuckoo (EVFCS)

Abstract

Node placement is one of the fundamental issues that affects the performance of coverage and connectivity in Wireless Sensor Network (WSN). In a large scale WSN, sensor nodes are deployed randomly where they are scattered too close or far apart from each other. This random deployment causes issues such as coverage hole, overlapping and connectivity failure that contributes to the performance of coverage and connectivity of WSN. Therefore, node placement model is develop to find the optimal node placement in order to maintain the coverage and guaranteed the connectivity in random deployment. The performance of Extended Virtual Force-Based Algorithm (EVFA) and Cuckoo Search (CS) algorithm are evaluated and EVFA shows the improvement of coverage area and exhibits a guaranteed connectivity compared to CS algorithm. Both algorithms have their own strength in improving the coverage performance. The EVFA approach can relocate the sensor nodes using a repulsive and attractive force after initial deployment and CS algorithm is more efficient in exploring the search of maximum coverage area in random deployment. This study proposed Extended Virtual Force and Cuckoo Search (EVFCS) algorithm with a combination of EVFA and CS algorithm to find an optimal node placement. A series of experimental studies on evaluation of proposed algorithm were conducted within simulated environment. In EVFCS, the algorithm searches the best value of threshold distance and relocated the new position of sensor nodes. The result suggested 18.212m is the best threshold distance that maximizes the coverage area. It also minimizes the problems of coverage hole and overlapping while guaranteeing a reasonable connectivity quality. It proved that the proposed EVFCS outperforms the EVFA approach and achieved a significant improvement in coverage area and guaranteed connectivity. The implementation of the EVFCS improved the problems of initial random deployment.

Keywords: Wireless sensor network, Node placement, Coverage hole, Overlapping area Extended Virtual Force and Cuckoo Search (EVFCS) algorithm

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List of Abbreviation

ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
CCP	Coverage Connectivity Protocol
CS	Cuckoo Search
EVFA	Extended Virtual Force-Based Algorithm
EVFCS	Extended Virtual Force and Cuckoo Search
FSA	Fish Swarm Algorithm
GA	Genetic Algorithm
GP	Genetic Programming
IPO	Individual Particle Optimization
PSO	Particle Swarm Optimization
QoS	Quality of Service
ROI	Region Of Interest
VFA	Virtual Force Algorithm
VFDEA	Virtual Force Based Deployment-Enhanced Algorithm
VFIPO	Virtual Force algorithm and Individual Particle Optimization
WSN	Wireless Sensor Network

CHAPTER ONE
INTRODUCTION

1.1 Background

In recent years, Wireless Sensor Networks (WSNs) have become one of the most promising technologies in sensing application environment. The WSNs provide flexibility in sensor nodes deployment and maintenance. Furthermore, it has the ability to be deployed in highly dynamic environments hence enable the sensor networks to be potentially used in a wide range of civilian and military applications [1], including security surveillance, environmental monitoring, habitat monitoring, hazard and disaster monitoring, health field applications, under-water communication [2], home applications such as smart environments and smart agriculture system [3-5]. The basic goals of a WSN generally depend on the application and have many functions which include determining the value of parameters at given location, to detect and monitor the occurrence of events and tracking an object. A wireless sensor network consists of distributed autonomous sensor nodes to cooperatively sense and monitor a physical or environmental condition, such as temperature, sound, vibration, pressure, motion or pollutants. In an environmental network [6], sensor nodes can be used to measure the temperature under atmospheric pressure, the amount of sunlight and humidity. The sensor nodes are also used to detect a vehicle movement, estimating the speed and direction of the vehicle. In a military sensor network, sensor nodes are used for battle surveillance [1] to track the enemies as they move through the geographic area covered by the network.

WSN consists of a number of sensor nodes and one or more base stations dispersed across a geographical region of interest (ROI). Each sensor has wireless communication capability and some level of intelligence for signal processing and data processing [7, 8]. In addition, with the integration of sensing, computation, and wireless communication capabilities, the sensor nodes can sense and monitor physical information from the environment, process the information, and report them to the base stations. The processed information is then linked to the outside world or to the end user via the Internet or satellites. A group of sensor nodes collaborate and transmit the information with each other through a single-hop or multi-hop communication. The multi-hop communication in a WSN environment is illustrated in Figure 1.1.

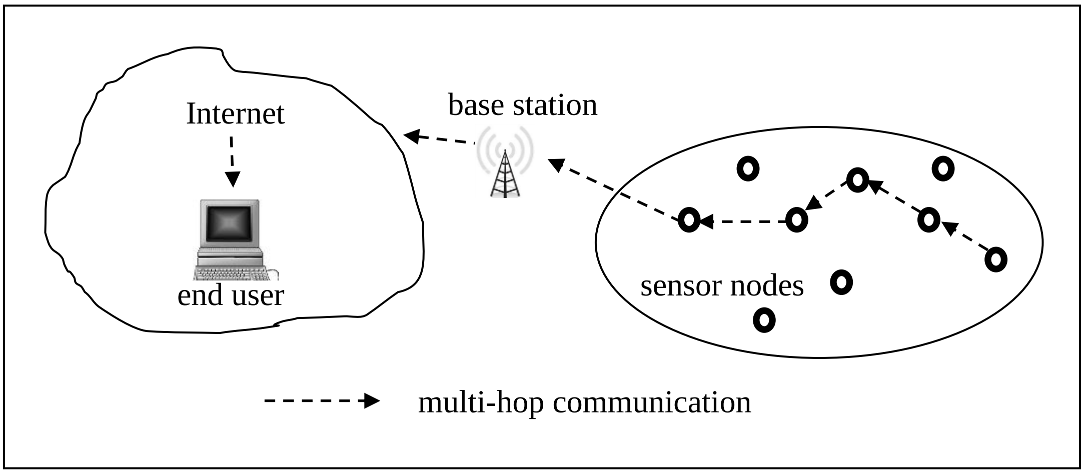


Figure 1.1: Wireless Sensor Network Environment

In WSN, node placement is the fundamental issue that affects the performance on the WSN application and its operations, and is closely related to the coverage and connectivity of the WSN nodes. According to [9], coverage is usually interpreted as how well a sensor network will sense and monitor the region of interest and is regarded as a measure of quality of service (QoS) in WSN applications. In addition, it is important to maintain the connectivity in order to have the best sensing coverage area. The areas of coverage and connectivity are closely related. Connectivity can be defined as the connection between sensor nodes that can communicate with one another to transfer information to the base station. However, sensors nodes are often randomly deployed and this had led to constraints such coverage holes, sensing overlapping and even connection failure. Connectivity and coverage problems are caused by the limited sensing, communication range as well as limited battery capacity. The node placement planning can be used to solve and improve the coverage and connectivity problem of sensor nodes.

1.2 Wireless Sensor Network

WSN consist of small, sensing, self-powered nodes which gather information or detect special events within a region of interest. The information gathered is then processed and transmitted to a base station using a wireless communication medium.

Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of applications [10]. The main function of sensor nodes is to sense or monitor the environment or event in the region of interest. Therefore, the coverage and connectivity of a sensor node are the major concern of WSN in evaluating the QoS of WSN applications [11]. According to [12], the positioning of sensor nodes affects coverage and connectivity performance of the WSN application. Coverage refers to the diameter of the sensing area covered by sensor nodes, while connectivity refers to the information transmission link from the target area to the base station. Due to the large number of sensor nodes used in WSN environment, the total cost for sensor networks deployment could be high. Therefore, it is important to optimize the placement of sensor nodes in WSN environment in order to achieve the adequate coverage and connectivity.

1.2.1 Coverage

Coverage is the most important feature of a WSN. Coverage is usually interpreted as how well a sensor network will monitor a region of interest [12]. It can be thought as a measure of quality of service (QoS) in WSN environment and its applications [13, 14]. The coverage of the monitored region can be maximized through proper planning of nodes density. Proper planning of node density can affect and coverage performance. Coverage problem is associated on how to ensure that each of the points within a region to be monitored is covered by the sensor nodes [14]. Coverage problems in WSN are basically caused by three main reasons; inadequate sensor nodes to cover the whole ROI, limited sensing range and random deployment [12]. Each sensor node can detect or monitor the environment within some very limited distance from itself. That distance is known as sensing range. In order to maintain the coverage area, the sensor nodes need to be placed not too close from each other so that the range of each node can be maximized. At the same time, it can also avoid sensing overlapping or redundancy that eventually results in overuse of the sensor nodes. However, due to the limited sensing range, the sensor nodes need to be placed not too far from each other to avoid coverage holes. The WSN goal is to have each location in the region of interest within the sensing range to ensure the region is covered by at least one sensor node.

Coverage can be measured in different ways depending on the application. Generally, there are many factors that influence the coverage performance in WSN such as deployment strategy, sensing range, communication range, positioning of sensor nodes and algorithm characteristic [8]. Proper design is required to ensure ample area within the ROI is covered while connectivity quality is maintained as this affects coverage performance.

1.2.2 Connectivity

In WSN, after collecting the information from the region of interest, sensor nodes need to transmit the aggregate data to the base station thru single-hop or multi-hop communication. Connectivity refers to the ability of sensor nodes in the network to communicate between with one another based on their routes and transmission distance. The sensor nodes exchange information within the environment of the monitored region. This information is made accessible to the external user through one or more base stations [15]. However, due to the limited communication capability, each sensor node has to act as router to help other nodes to forward the information to the base stations [16]. Therefore, it is important to ensure that every sensor can communicate with each other directly or via relay nodes to the base station. Two sensor nodes are said to be connected if they are located within the communication range of each another [17]. A network is said to be fully connected if every sensor node pair can communicate with each other. Hence, connectivity affects the robustness and throughput of the wireless sensor network [18].

1.2.3 Node Placement

The first step required in WSN is to design the placement of sensor nodes within a sensor network field. Sensor node placement is vital to ensure the tradeoffs between optimal coverage and acceptable connectivity quality is achieved within the monitoring area. The ways of the sensor placement are closely related to the WSN application and functions [19]. According to [20], placement of sensor nodes will give a dramatic impact on the effectiveness and efficiency of the WSN. Sensor nodes can be placed in deterministic or random position. Ishizuka and Aida [21] stated that when a lot of sensor nodes are placed in a large area, it is not realistic to place them all at predetermined position, hence, randomly placement is chosen. Furthermore, sensor nodes placement will affect the coverage and connectivity in the monitoring area but by placing too many sensor nodes within region of interest is not the best solution. Therefore, the optimal node placement approach is used to maintain the coverage area while maintaining the connectivity based on distance and sensing range of sensor nodes.

1.3 Research Motivation

Coverage and connectivity are the fundamental issues related to random deployment in WSN application. Sensor nodes are deployed randomly in the region of interest and caused problems such as coverage holes, overlapping and connectivity failure. These problems affect the performance, operation and QoS in WSN applications and environments. A sensor node has a limited radius of sensing and communication range. Due to random deployment, some of the sensor nodes could deployed too close to each other while others are too far apart. This situation gives an impact to coverage and connectivity of these nodes. Some area may not be covered by a sensor node and some will have the overlapping of sensing area.

Node placement is closely related to the coverage and connectivity, and gives an impact to WSN applications. This scenario has presented the motivation for the problem to be solved by proposing an algorithm to find an optimal node placement as a solution of coverage and connectivity problem in random deployment of sensor nodes. The mobile sensor nodes that are attached to autonomous robots are used as an alternative to discover the problem of coverage holes, overlapping and connectivity failure.

1.4 Problem Statement

Sensor nodes deployment in WSN can be achieved through deterministic or randomly placement strategies. Deterministic placement of sensor nodes is easier to implement rather than random deployment [9]. Deterministic approach is mostly used in a small and friendly environment. In many WSN applications however, sensor nodes are deployed randomly due to various factors such as inaccessibility of terrain, large scale of the network impractical or infeasible to deploy the sensor nodes in deterministic way and etc. Due to these reasons, sensor nodes are deployed randomly in a distributed, sophisticated and independent manner. For example, WSN applications used in military missions, disaster recovery or forest fire detection need to be randomly deployed as the areas involved are very risky and infeasible to place the sensor node in deterministic deployment. The best option therefore is by placing the sensor nodes randomly by scattering the nodes from an aircraft over the region of interest. However, random deployment of sensor nodes in a non-invasive does not fulfills the coverage and connectivity requirement since it is impossible to configure the exact locations for the sensor nodes [22]. Thus, the situation may lead to coverage and connectivity problem such as coverage holes, overlapping and connectivity failure.

The first step required in WSN is a proper design of node placement within the sensor network field [23]. Sensor nodes placement is the key of WSN surveillance as it considers the sensing coverage of monitoring area and connectivity for data transmission to the base station. According to [24], placement of sensor nodes gives an impact to the effectiveness and efficiency of WSN. Hence, node placement is the fundamental issue that needs to be addressed as it affects the coverage and connectivity in the WSN applications and operations. In WSN, the main issue when deploying an efficient sensor network is to find the optimal node placement strategies. Crucially, WSN requires the node placement of sensor network to be designed. The way of the sensor placement is related to the WSN applications and environment. The optimal node placement approach is used to maintain and guarantee optimal coverage area and satisfactory connectivity in a region of interest. The sensor nodes used in WSN have several constraints such as restricted sensing and communication range as well as limited battery capacity. These limitations bring some issues such as data aggregation, coverage, connectivity, network lifetime and scheduling in WSN environment [25]. Both coverage and connectivity problems are caused by the limitation of sensing and communication range. In order to solve both problems, the solution must consider on how the sensor nodes are positioned in the region area to ensure a coverage and connectivity are guaranteed [26, 27].

The first concern in deploying sensor nodes in WSN is the coverage degree in the monitoring region of interest (ROI). The coverage issue is a fundamental problem for wireless sensor networks [28, 29]. Coverage is considered as an important measure of quality of service provided by WSN. The first requirement concern in coverage area is to guarantee that any event or condition change at any target point in a given area can be sensed by at least one sensor node. According to [12, 30, 31], coverage problems in WSN is basically caused by three main reasons namely (i) inadequate sensors to cover the whole ROI, (ii) limited sensing range and (iii) random deployment. A sensing range of sensor node is restricted to certain radius which consequently brings the coverage problem. By increasing the radius and placing many sensor nodes in the monitoring area can enhanced the coverage area but this is costly and not the best way [31]. In random deployment, some of the sensor nodes are deployed too close to each other while others are too far apart which cause to coverage problem. The sensing capabilities of the sensor nodes are wasted due to the closeness of sensor nodes that would eventually cause sensing overlapping while nodes far apart from one another cause coverage holes.

The second requirement concerned is the connectivity. Due to the multi-hop communication, the information may be processed and aggregated by several sensor nodes and forwarded to the base station [26]. Connectivity also can be defined as the ability of the sensor nodes to transmit and report the information from the monitoring area to the base station. If there is no available route due to connectivity failure between sensor nodes, the data collected by the sensor nodes cannot be processed and transmitted to the base station. Each sensor node has a communication range which defines the area in which another sensor node can be located in order to receive and transmit the data. This is different from the sensing range which defines the monitoring area of the sensor node. A sensor network is said to be 1-connected if at least one path between any two sensor nodes. The coverage area and connectivity are closely related in WSN environment. An important principle that must be considered is the sensing and communication range where communication range, R_c, is at least twice of the sensing range, R_s, then the coverage of an area implies the connectivity. This rule is very useful in placing the sensor nodes in a WSN [9]. According to [30], deployment of too many sensor nodes is not the best solution in order to maintain the coverage area and connectivity due to sensor cost and may result in non-optimal use of several sensor nodes. Coverage and connectivity problems are caused by the limitation of sensing and communication range [28]**.** In order to solve both problems, the optimal placement of the sensor nodes must be considered to maintain the coverage area and connectivity between the sensor nodes. The restricted sensing radius consequently brings the coverage problem. By increasing the radius and placing too many sensor nodes can enhance the coverage area but this is very costly. As illustrated in Figure 1.2, it also may cause the coverage hole and the sensing overlapping due to the random deployment of the sensor nodes.

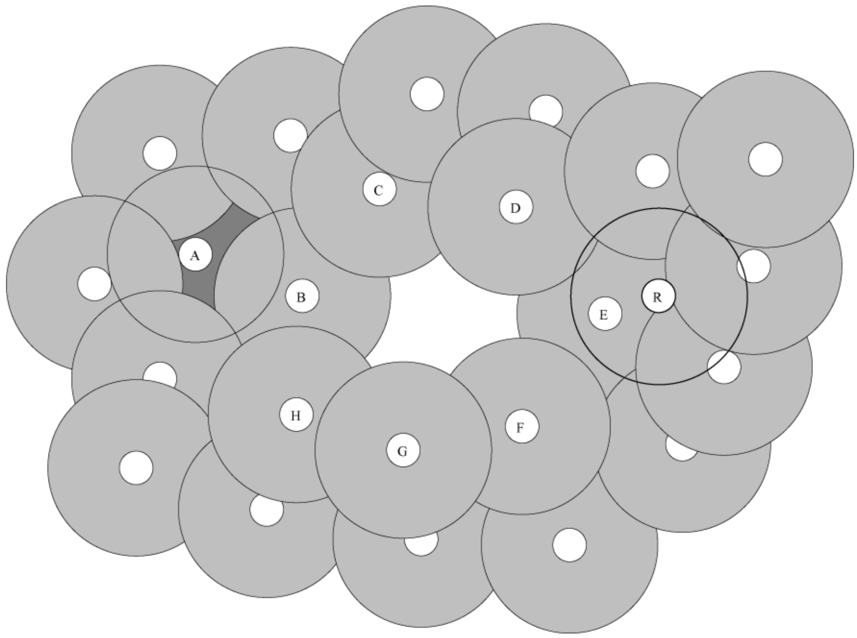


Figure 1.2: Coverage Hole and Overlapping

In Figure 1.2, *A* to *G* and *R* refer to sensor nodes. Sensor node *A* is located in a coverage hole (dark shaded), where it is located far apart from other nodes. *R*, is an example of a redundant sensor within an area where its range overlaps with other nodes.

From the connectivity point of view, large distances between nodes will weaken the communication links, lower the throughput and increase the energy consumption.

The Virtual Force Algorithm (VFA) has been used to overcome the coverage problem in random deployment [32, 33] where the sensor nodes are relocated after the initial random deployment. However, the VFA approach considers only the coverage aspect. Thus, [34] has proposed an Extended Virtual Force-Based Algorithm (EVFA) using an ideal threshold distance value, $\sqrt{3}R_s$ in order to improve the connectivity problem in the original VFA. The coverage and connectivity problems in random deployment can be improved from the EVFA using a best value of threshold distance instead of $\sqrt{3}R_s$ in order to minimize the coverage hole and overlapping with a maximum coverage area and a guaranteed connectivity. To address this problem, the suitable planning needs to be conducted to ensure that the sensor field has maximum coverage area while coverage holes and overlapping remain minimum. The sensor nodes need to be placed in a position such that the sensing capability of the network is fully utilized to ensure high quality of service. Therefore, these coverage and connectivity problems need to be addressed during the node placement phase.

1.5 Research Question

This research focuses on providing answer for the following problem:

a. How the placement of sensor nodes ensuring the coverage in random deployment?
b. How the placement of sensor nodes guaranteed the connectivity in random deployment?

1.6 Research Objective

The main objective of this research is to develop an algorithm for optimal sensor nodes placement in wireless sensor network. The sub-objectives are:

a. to develop an EVFCS algorithm in order to maintain the coverage and guaranteed the connectivity in ROI;

b. to evaluate the EVFCS algorithm in term of coverage and connectivity.

1.7 Scope of the Research

The scope of this research is focused on finding the optimal node placement in wireless sensor network (WSN) field. In this thesis, the sensor nodes are assumed to be deployed using a random deployment scheme in an area of 100 x 100 m over an open space area with no obstacles between all nodes. The experiment was conducted using simulation. The area of 100 x 100 m is used by most researchers in conducting a simulation to practically represent the WSN environment with a limited number of sensor nodes [34-37]. The sensor nodes used are consisting of dynamic homogeneous node with the same sensing and communication range. The sensor nodes can be relocated after the initial deployment and assumed to have limited movement and are attached to the autonomous mobile robot. The autonomous mobile robots are equipped with various sensor nodes and possess communication capabilities. These robots can be used and act as high-performance mobile sensor nodes in WSN [38]. The autonomous robots grasp the environmental circumstances using various sensor data obtained from the WSN, and use these data in several different tasks.

1.8 Research Contribution

Sensor placement planning is a very important issue for sensor deployment. In random deployment there are several problems due to the random distribution of sensor such as coverage holes, overlapping and connectivity failures. Due to these problems, the sensor node placement algorithm was developed. The solution can be used to maintain the coverage area and connectivity in the first phase of sensor nodes deployment in WSN. The algorithm can be used as an alternative solution in WSN application with random deployment scheme.

1.9 Organization of Thesis

This thesis is organized as follows. Chapter One states the background of the research, the objectives, the scope and contribution of the research. Chapter Two consists of literature review and the similar work done by others. In Chapter Three, the methodology adapted is described thoroughly. The analysis and result are presented in Chapter Four and Chapter Five. The discussions with the conclusion are justified in Chapter Six.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

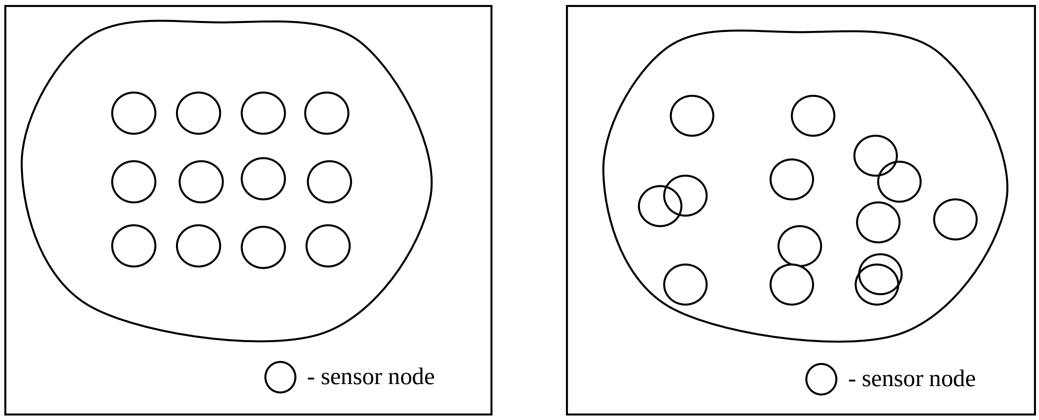
Wireless Sensor Networks (WSNs) have been used in sensing, monitoring and tracking applications. Sensor node deployment is a critical issue as it affects the performance, detection capability and also cost in WSN applications. Sensor nodes can be deployed in two schemes, either deterministic or random deployment. However, for large-scale WSNs, deterministic deployment is not practical and impossible to be implemented. Sensor nodes are deployed randomly by dropping the sensor nodes from the plane. Due to random deployment, coverage and connectivity constraints such as a coverage holes, overlapping and connectivity failure occur. The limitations or restrictions in sensing and communication range as well as limited battery capacity also affected the coverage and connectivity performance. Node placement planning needs to be executed to solve the coverage and connectivity problem and improve the performance of sensor nodes.

2.2 Coverage

Coverage is a fundamental requirement in WSN and reflects on how well the sensor nodes monitor a region of interest [12]. WSN needs to guarantee that the monitored region is completely covered with a high degree of sensing capability [17]. Coverage therefore, is the key performance and quality of service metric measurement in WSN [39]. The design of coverage scheme is different in each of the WSN application depending on the objectives and application's requirements. The main goal is to have each location in the region of interest within the sensing range and at least covered by one sensor. Generally, there are many different factors that influence the coverage performance of WSN. The following sections discuss the important dominating factors as mentioned in [8].

2.2.1 Deployment Strategy

Sensor nodes are deployed in an area either in deterministic or random manner. Deterministic deployment is easier to develop and can be implemented in grid deployment. Sensor nodes can be placed in predetermined locations and is strongly tied to the application they are deployed for. In most cases, deterministic approach is used in the small and friendly environment [18]. In applications such as battlefield surveillance and environmental monitoring, sensor nodes may be dropped from airplanes. These sensor nodes cannot be expected to fall exactly at predetermined locations [40]. Due to the large scale deployed particularly in remote or inhospitable areas, predetermined deployment is not suitable and impossible to be implemented. Therefore, random deployment is adopted where the sensor nodes are randomly deployed in a distributive, sophisticated and independent manner. The examples of deterministic and random deployment are shown in Figure 2.1(a) and Figure 2.1(b) respectively.



a) Deterministic Deployment   b) Random Deployment

Figure 2.1: Deployment Strategies in WSN

In some environment, random deployment often becomes the only option and most practical way in placing the sensor nodes. Deterministic deployment for WSN applications such as in military missions, disaster recovery and forest fire detection is very risky and infeasible [41]. In military operations, random deployment is the only option where the sensor nodes are deployed by dropping from the helicopter, or launched into the battlefield using grenade launchers or cluster bombs. One of the appealing aspects of WSN is the ability to be randomly deployed without the need to do it manually. However, in random deployment, a coverage problem will arise [42]. The coverage can be enhanced by manipulating the locomotion capability of the sensor nodes or by using incremental deployment after the initial deployment [30].

Song et al. [43] works with random sensor nodes deployment to improve the quality of service (QoS) and optimize the distribution of mobile nodes. The authors stated that WSN is often used in inhospitable and inaccessible environment to monitor activities, gather and report information about the target environment. Therefore, the random deployment in the target region is considered a very significant approach to address the problem. Filippou et al. [44] also used random deployment for large scale WSN environment and redundant nodes were used to increase connectivity, coverage and to prolong network lifetime.

According to [45], random deployment refers to the situation in which sensor nodes are uniformly and independently distributed across the monitored field. In random deployment approach, the success of WSN applications depended on the deployment quality that uses the minimum number of sensors to achieve a desired coverage. The authors investigated the coverage over estimation and address the challenge of designing coverage-guaranteed deployment strategies. The research also focused on guaranteeing coverage by using the minimum number of sensor nodes randomly. In reality, the sensor nodes are impossible to be deployed using the deterministic approach in large scale obstructed area. Some problems might arise due to random deployment that affects the quality of service in WSN application. This thesis focuses on random deployment of sensor nodes while trying to minimize the problems related to coverage and connectivity.

2.2.2 Types of Nodes

In WSNs applications, the set of nodes used can be either a homogeneous or heterogeneous node. Ideally, different sensor types are assumed to have different sensing ranges. It is generally assumed that a sensor node consumes more energy when it uses a larger sensing range. A homogeneous node is a node that has the same capabilities. All homogeneous nodes have a uniform sensing and communication range. In contrast, a heterogeneous node possesses different capabilities, are more powerful than other nodes and known as cluster head. Heterogeneous sensor nodes have difference sensing ranges where every sensor node varies between each other. WSN lifetime is proportional to energy. The more energy a node has, the longer the application is up. Ranjan and Kar [46] provided a method for determining the optimal number of cluster heads for homogeneous using reasonable energy consumption model. Therefore, this thesis considers only the distribution of homogeneous nodes so that the sensing range is uniform between sensor nodes.

2.2.3 Sensing Range

A disk coverage model is the most popular coverage model used in WSN. A sensor node coverage area is usually modeled as a disk. Each sensor node can only detect an object or phenomena in a limited range which is called as sensing range, R_s. The sensing range, R_s, is used to characterize the sensing capability of a sensor node. Any point within sensing range can only be sensed and covered by a sensor node. The sensor nodes have uniform transmission range and sensing range. Wang et al. [24] used the disk coverage model to configure a network to achieve guaranteed degrees of coverage and connectivity where the covered area is based on sensing range and Euclidean distance between sensor nodes and the point. The authors also defined the sensing circle *C*(*v*) of node *v* as the boundary of node v's coverage and assumed that any point *P* on the sensing circle C(*v*) (i.e., $|Pv| = R_s$) is not covered by sensor node *v*. Huang and Tseng [47] simulated the coverage problem to determine whether every point in the service area of the sensor network is covered by at least *k* sensor nodes. The disk coverage model with sensing range and Euclidean distance also had been used to define the coverage problem. Figure 2.2 shows the sensing range of sensor nodes *X* as XR_s and for sensor node *Y* as YR_s. The target point *P*, is covered by the sensor nodes *X* if the Euclidean distance between a sensor *X* and target point *P* is within the sensing range of sensor node *X*, XR_s. On the other hand, the target point, *P* is considered uncovered by sensor node *X* if the Euclidean distance between sensor node *X* and target point, *P* is more than sensing range of sensor node *X*. In the disk coverage model, the sensing range is the key measurement of the coverage area.

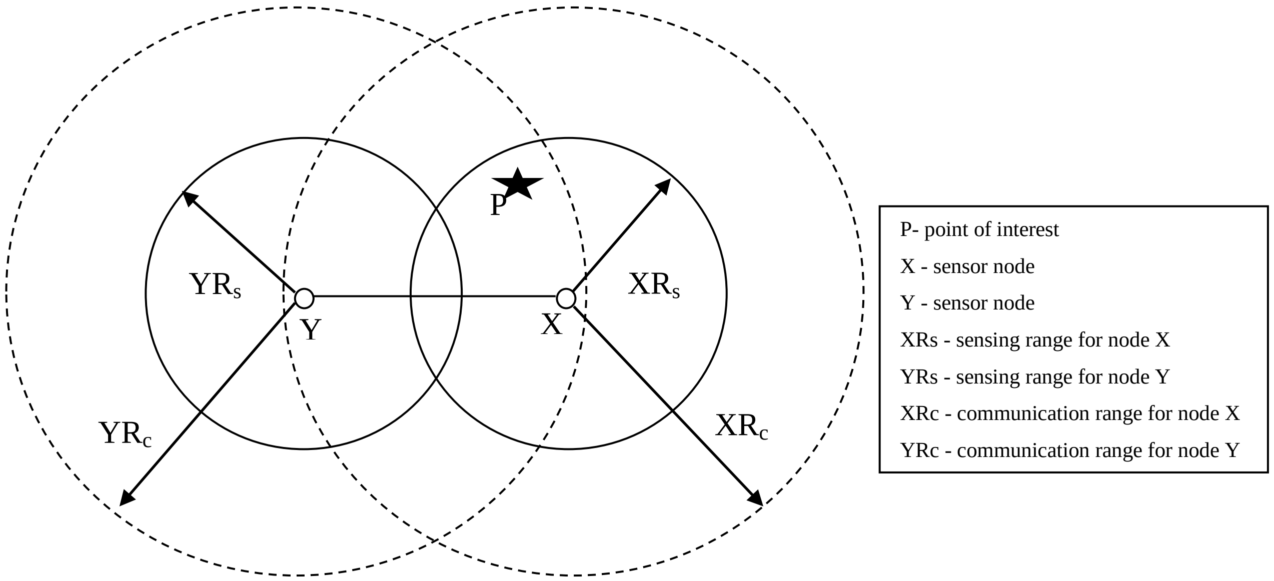


Figure 2.2: Sensing and Communication Range

2.2.4 Communication Range

Similar to the sensing range, as shown in Figure 2.2, two sensors, *X* and *Y*, are able to communicate with each other if the sensor falls within the communication range of the other sensor. Sensor nodes can communicate with each other based on communication range and Euclidean distance between sensor nodes. Two sensor nodes are said to be collaborating if the Euclidean distance between sensors is less than R_c and not more than twice the sensing range. If the distance between sensor nodes are more than communication range, R_c, the communication link within sensor nodes is not connected. In Figure 2.2, the sensor node *X* and *Y* are said to be connected where the distance between sensors is not more than twice of the sensing range otherwise both sensor nodes are not connected. In the Euclidean distance point of view, both sensor nodes are not more than communication range, R_c, therefore both sensor are said as connected. Zhang and Hou [48] defined communication range and sensing range as a parameter of maintaining the coverage and connectivity. They also proved that if the communication range is at least twice the sensing range, complete coverage of a convex area implies connectivity among the working set of nodes.

2.2.5 Sensor Mobility

Sensor node can also be categorized into static or dynamic node. Static nodes are nodes whose locations remain unchanged and are unable to relocate once they are deployed. Dynamic nodes however, are nodes whose location changes and can be relocated after deployment. The sensor node can be attached to the autonomous robot to perform motion control of the mobile node. Figure 2.3 illustrates the autonomous robot attached with sensor nodes that can be used to navigate and sense the information in a WSN environment.

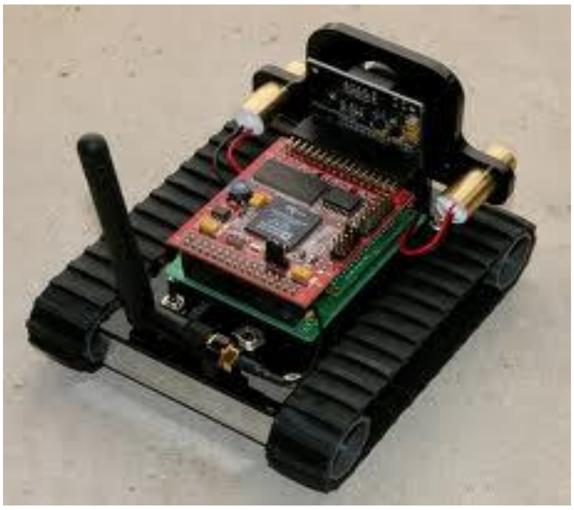


Figure 2.3: Autonomous Mobile Robot

The mobility of the sensor nodes may impact the overall network performance. Mobile nodes have the ability to sense, compute and communicate [49] similar to static nodes. However, a key difference is mobile sensor nodes have the ability to reposition and organize itself in the network [18]. Sensor nodes can be moved towards the positions that have poor coverage or towards the disconnected areas and dynamically reposition based on the objective of deployment [50].

Soua et al. [22] proposed to use a mobile robot to assist the initial sensors deployment and to improve sensing coverage and connectivity of monitored area. In [51], the moving sensor is used in random deployment to meet the coverage and target detection and the results show that sensor mobility can improve the network coverage. Liu et al. and Fletcher et al. [51, 52] showed that sensor mobility can be exploited to compensate the lack of sensor nodes and improve the network coverage. Mobile sensors can significantly improve network performance by moving to locations where there is a coverage hole [53]. Asim et al. [54] proposed a novel sensor relocation scheme where redundant mobile nodes are moved to minimize coverage holes in the network. The mobile devices can be used as an orthogonal method to address the network connectivity, coverage, and network life time problems in WSNs. Mobile sensors are useful as they can move to locations that meet sensing coverage requirements. Wang et al. [55] had investigated the problem of placing mobile sensors to get high coverage. In the study, the authors designed two sets of distributed protocols for controlling the movement of sensors that support the communication and movement based on Voronoi diagrams. Mobile sensor nodes have a larger appeal when it comes to deployment due to its mobility. Static nodes on the other hand cannot be relocated after its initial deployment. Bin et al. [37] used the mobility of the nodes to move redundant nodes to the uncovered or weak-covered areas. The simulation results show that the sensor's mobility in the limited region can realize the coverage optimization and improve the coverage performance of the network. Static nodes however, are not the preferred choice as random, scattered deployment of static nodes will lead to coverage hole and sensing overlapping. In this study the mobile sensor nodes were used as the best alternative to relocate the position of sensor nodes in order to maintain the coverage and connectivity while minimizing the coverage hole and overlapping area.

2.3 Coverage and Sensing

A sensor node's coverage area is usually modeled as a disk. Each sensor node can only detect an object or phenomena within a limited range which is called as sensing range, R_s. Due to the limited range, it caused coverage problem known as coverage hole and overlapping. Both problems can affect the performance and QoS of the WSN application [30].

2.3.1 Coverage Hole

WSN are commonly deployed in a large scale area or inaccessible terrain. A random deployment is the best option in these cases where sensor nodes are usually dropped from the aircrafts. However, random deployment caused some of the sensor nodes to be placed too close to each other while others to be far apart. The density of sensor nodes is not uniform so some areas are not covered by the sensor nodes which are commonly known as coverage hole [8, 30, 56]. A coverage hole that exists in WSN environment is very important and must be addressed to increase the QoS and accuracy [57]. Therefore, the problem of coverage hole can be solved by increasing the density of static sensor nodes or the sensitivity of the sensor nodes. Autonomous mobile robot-assisted sensor deployment can be used in random deployment strategy. Fletcher et al. [52] used bare robots to improve the coverage area of an existing random WSN by transferring redundant sensor nodes to report the coverage hole positions. However, the former choice implies a higher cost. An alternative approach is by employing mobile nodes in the network. The mobile sensor nodes can be used to minimize the coverage hole after the initial sensor deployment [8, 51]. Asim et al. [54] stated that mobile sensor nodes can be used as an alternative to minimize the coverage holes in the network of random deployment. Mobile sensors are useful as they can move to the location that meets the sensing coverage requirement. The authors proposed a novel sensor relocation scheme where redundant mobile nodes are moved to minimize coverage holes in the network.

2.3.2 Overlapping

A WSN environment may consist of hundreds to thousands of sensor nodes which were deployed randomly. Due to the random deployment, it is common that the area covered by the sensor nodes may overlap with each other even if the nodes are uniformly distributed. The overlapping or redundant sensing of coverage will waste the sensing capability, the number of sensor nodes and also the sensor nodes energy. Figure 2.4 shows the intersection of sensing ranges of two sensor nodes. The intersecting area is called an overlapping area. Redundant sensor nodes will sense the same target point, so in this case, both sensors will consume their energy for ranging and sensing and transmit the information to the base station. This not only wastes the energy but also increase the number of nodes required. This problem can be overcome by relocating the sensor nodes if there are overlapping area using mobile sensor nodes [8].

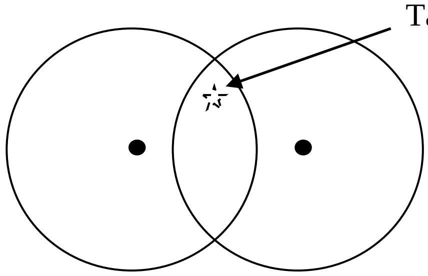


Figure 2.4: Overlapping between Two Nodes

Coverage is the major consideration in WSN environment as it affects the quality of service of a WSN application. In random deployment, the coverage is the prior consideration because of the random placement of sensor nodes will affect the coverage area and performance. The use of the mobile sensor nodes can help to minimize the problems occurring in random deployment scheme. Many researchers used mobile sensor nodes in order to overcome this problem. Mateska and Gavrilovska [50] proposed an algorithm for reorganization of the mobile sensor nodes positions, after the initial random placement, in order to improve the network coverage and the connectivity known as C2 algorithm. The algorithm initially organizes the network in a clustered topology, assuming hexagonal grid structure. The algorithm chooses the optimal nodes to perform the movements, maintaining the connectivity between the sensor nodes and minimizing the energy that the nodes consume for their movement. The simulation results show the benefits of the proposed algorithm implementation for coverage and connectivity improvement in a homogeneous WSN.

Aziz et al. [58] proposed a new algorithm to optimize sensor coverage using Particle Swarm Optimization (PSO) and Voronoi diagram. The proposed algorithm used the PSO to find the optimal deployment and provide the best coverage area while the fitness of the solution is evaluated using the Voronoi diagram. The simulation result shows that the proposed algorithm achieves a good coverage with a better time efficiency. Fan and Jin [8] stated that the full coverage area is not guaranteed due to random deployment, resulting in accumulation and redundant of sensor nodes at certain area of the sensing field while leaving other area with a coverage hole. The authors stated that to overcome the problem of coverage holes, it could either increase the number of static nodes or increase the sensing range sensitivity of the sensor nodes. Increasing static nodes is not the best option as it implies a higher cost and excessive radio interference. An alternative approach to address the problem is to employ mobile nodes in deployment, e.g. nodes mounted on autonomous robots.

Wang and Tseng [59] implemented the solution of node placement problem that consider both the binary and probabilistic sensing models. The solution also allows an arbitrary relationship between the communication distance and the sensing distance of sensor nodes. The authors proposed two schemes which are competition-based scheme and a pattern-based scheme. The competition-based scheme allows mobile sensor nodes to bid for their closest locations, while the pattern-based scheme allows sensor nodes to determine the target locations on their own. Both schemes proposed are very efficient in terms of number of sensor used. The study proved that the coverage problem in random deployment need to consider a few parameters such as sensing range, type of nodes and mobility of the node in order to achieve the requirement of the coverage performance. As an alternative to minimizing the coverage hole and sensing overlapping in random deployment, mobile sensors will be used because it has the locomotion capabilities with the ability to self-deploy and self-repair.

2.4 Connectivity

In a multi-hop sensor network, communication between sensor nodes are linked by a wireless medium such as radio, infrared, or optical media [26]. After collecting information from the environment, sensor nodes need to transmit the aggregated data to the base station. Connectivity between sensor nodes are important to ensure that every sensor node can communicate with the base station [60]. Connectivity affects the robustness and achievable throughput of communication in a sensor network [61]. Due to the multi-hop communication of WSNs, a network is said to be fully connected if every pair of nodes can communicate with each other [62], either directly or via intermediate relay nodes.

A network of sensors is considered to be connected only if there is at least one path between each pair of nodes in the network [62]. Figure 2.5 shows the connectivity between nodes in multi-hop communication to the base station. This is only possible if there is a path from each node to that base station. According to [63], connectivity depends primarily on the existence of paths and affected by changes in topology due to mobility, the failure of nodes, and attacks that cause by loss of links, the isolation of nodes, the partitioning of the network, the upgrading of paths and re-routing. Due to the large number of sensor nodes in a WSN, the total cost could be high for the whole network, even the cost of each individual sensor node is low. Therefore, it is important to find the minimum number of nodes required for a WSN to achieve the connectivity while optimizing the coverage at the same time.

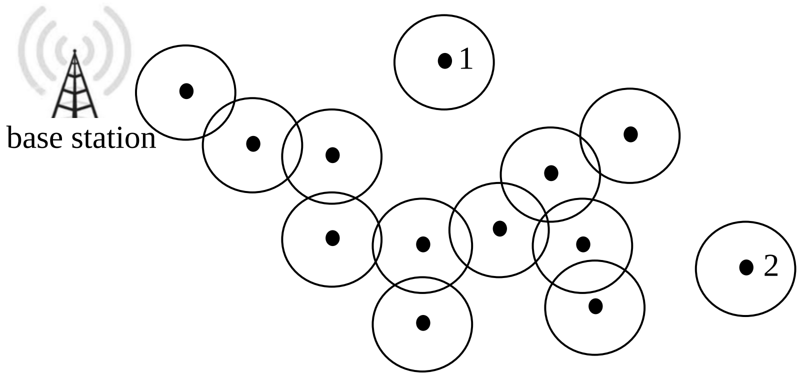


Figure 2.5: Connectivity between Nodes to the Base Station. Node 1 and 2 Are Not Connected.

2.5 Relationship between Coverage and Connectivity Sensing Model

Since the WSN goal is to sense and monitor the phenomena within the ROI, the measure of sensing coverage is important. The sensing ability within the sensing area is always assumed as deterministic where every point within the sensor range can be sensed by other sensors.

2.5.1 Disk Sensing Model - Coverage

The most commonly used approach to model a sensor coverage model is a disk sensing model [64]. All points within a disk, centred at a sensor are considered to be covered by the sensor. Any point within the area in a disk sensing model is assumed to be sense by the node. Generally, the sensors are assumed to have the same range. Each sensor node can only detect an object or phenomena in a limited of sensing range R_s. Any object within the disk of radius or sensing range, R_s, center is reliably detected by it. Wang [65], stated that the coverage function of the disk coverage model is given by:

$$f\big(d(s,z)\big)\begin{cases}1, & if d(s,z) \le R_s \\ 0, & \text{otherwise}\end{cases} \tag{2.1}$$

where $d(s, z)$ is the Euclidean distance between a sensor s and a space point z, and the constant R_s>0 known as sensing range. A disk or sensing disk model is as shown in Figure 2.6 where the center is the sensor node, s with the radius of the sensing range, R_s. The disk coverage model is an omnidirectional coverage model. All space points within a disk are covered by this sensor. On the other hand, all space points outside a disk are not covered by this sensor. The sensing range, R_s, is used to characterize the sensing capability of a sensor.

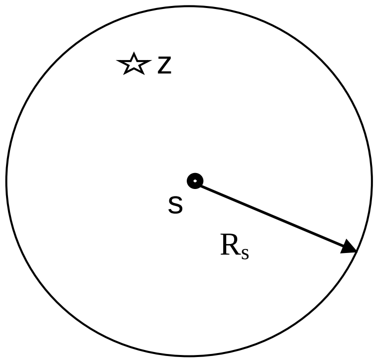


Figure 2.6: Disk Coverage Model

The coverage model measures the sensing capability and quality by capturing the geometric relation between a space point and sensor nodes. In almost all cases, a sensor coverage model can be formulated as a function of the Euclidean distances between a space point and sensor nodes [65]. According to [66, 67], a sensor node placed at a location point (x_1, x_2) can cover a location point (y_1, y_2), if the Euclidean distance between these two points is

$$d\,(x, y) = (x_1 - y_1)^2 + \,(x_2 - y_2)^2 \leq {R_s}^2 \quad (2.2)$$

where, R_s is the sensing range of the sensor. Wang [65] also introduce the concept of coverage function in the context of a two-dimensional plane. The author considers a space point z, and a set of sensor nodes, $S = \{\}$ and used $d(x, y)$. $(d(x, y) \geq 0)$ to denote the Euclidean distance between a sensor s and a space point, and in the two-dimensional space

$$d(x, y) = (x_1 - y_1)^2 + (x_2 - y_2)^2 \tag{2.3}$$

where (x_1, x_2) and (y_1, y_2) are the Cartesian coordinates of the sensor s and the space point z.

2.5.2 Disk Sensing Model - Connectivity

Similar to the sensing range, as shown in Figure 2.2, two sensors, ***X*** and ***Y***, are able to communicate with each other if the sensor falls within the communication range, R_c, of the other sensor node. Two sensor nodes at the distance of R_c or less can communicate reliably. In addition, a coverage implies a connectivity which the sensing range is at least twice the sensing range [24, 48]. The theorem and proof of condition which coverage implies connectivity are as stated below:

Theorem:

The condition that communication range is at least twice of the sensing range is both necessary range to ensure that coverage implies connectivity.

Proof:

The condition to ensure the connectivity will give the full coverage is

$$R_c \leq 2R_s$$

The coverage does not imply connectivity if $R_c > 2R_s$ but coverage guarantees connectivity if $R_c \leq 2R_s$.

Figure 2.7 illustrated the scenario of $R_c \geq 2R_s$ and $R_c < 2R_s$.

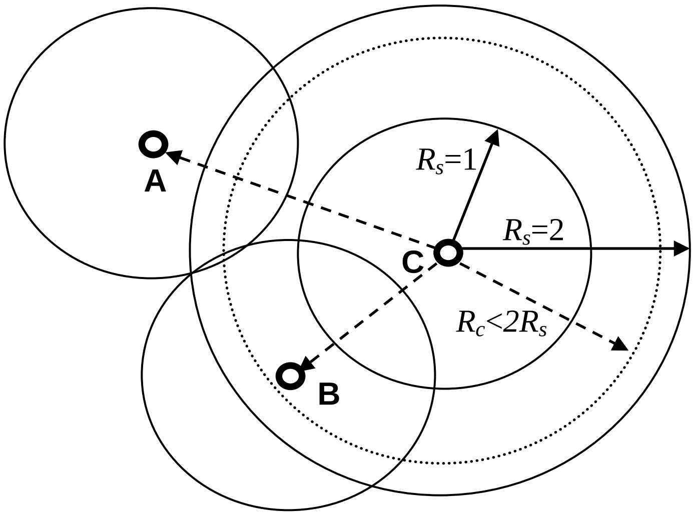


Figure 2.7: Disk Based Sensing Model

Figure 2.7, shows that *A*, *B* and *C* are sensor nodes with a sensing range, R_s, and communication range, R_c. Sensor nodes *B* and *C* are connected since the distance between node *B* and *C* is less than $2R_s$. Wang et al. [24] proved that the Coverage Connectivity Protocol (CCP) also does not guarantee connectivity when the ratio of the communication range to the sensing range is less than $2R_s$. Refer to the $R_c \geq 2R_s$, the sensor node *A* and *C* is said not to be connected.

Apart from coverage, connectivity is also one of the matrices to measure the quality of service in a WSN. Connectivity is important to transmit the information from the coverage area to the base station. Connection failure will affect the WSN performance. Asim et al. [54] described failures in sensor networks are common and can be addressed by using redundant nodes in the network. By moving mobile redundant nodes or activating any sleeping redundant nodes in the group can be the alternative to overcome the failure of sensor nodes. Sensor nodes failure may cause connectivity loss and network partitioning. The authors claimed that this situation can be solved by injecting a few mobile nodes in the network which can be moved to desired locations and repair broken network or using redundant nodes in the network to minimize the connection failures. Due to the cost of the sensors, deploying too many redundant sensor nodes is not practical. This problem however, can be solved by optimizing the minimum number of nodes. In addition, the positions of the sensor nodes need to be well planned to make sure every sensor node is connected and reachable to the base station.

2.6 Node Placement Technique

The node deployment strategy decides what type of sensor node is needed and where it should be deployed in order to achieve performance that meets the user's requirements [68]. The placement of sensor nodes will affect the numerous network performances metric such as coverage, connectivity and energy consumption [19]. Ghosh and Das [26] stated that coverage and connectivity are two fundamental factors in WSN and are considered as a metric of interest for targeting and providing a better QoS in WSN applications. Area coverage and connectivity in wireless sensor networks are both related to metric performance in WSN. Connectivity and coverage problems are caused by the limited communication and sensing range. To solve both problems the solution lays in how the sensors are positioned with respect to each other [69]. Table 2.1 summarized the performance metric of coverage and connectivity studied by researchers.

Table 2.1: Related Studied on Coverage and Connectivity in Node Placement

Method / Technique	Description	Authors
• Optimal 3D Grid Deployment (O3D)	• the device deployment plays a key role in the performance of any large-scale in a forestry space that consider several fundamental factors such as coverage and connectivity.	[70, 71]
• Mobile sensor assisted network architecture	• proposed a mobile sensor assisted network architecture with an optimal algorithm for calculating the coverage contributions in node placement	[72]
• Sensors deployment enhancement by a mobile robot	• enhancing coverage is important for sensor networks to provide continuous sensing services. • addressed the problem of redeploying sensors in a target field to maximize the sensing coverage. • designed an approach to relocate sensors from densely deployed areas (redundant sensors) to sparsely deployed areas where coverage holes are present based on mobile robot	[22]
• Grid-based sensor networks	• analyzes several sensor deployments and computes their efficient coverage areas and their efficient coverage area ratios	[69]
• Movement strategies in node placement	• the coverage problem is heavily dependent on the coverage model of individual sensor and the locations of the deployed sensor nodes • network coverage is an important performance metric for various applications in WSNs	[73]

When the sensor nodes are placed in a large area, it is not realistic and impossible to place them all at predetermined or deterministic positions. Instead, random deployment is needed. In the randomly deployment, the coverage and the connectivity requirements cannot be guaranteed since it is impossible to configure the exact location of each sensor. Thus the random deployment may result in having the coverage hole, overlapping as well as in connected or disconnected nodes [50]. Recently, mobility of sensor nodes has been introduced for improving coverage in WSN. Each sensor is attached to a certain mobile platform, e.g. autonomous robot, and obtains the ability to geographically relocate [52]. Mobile sensor nodes can be used to overcome this problem [54]. In random node deployment, mobility of the sensor nodes may impact on the overall performance of coverage and connectivity. Another way to improve network coverage and connectivity is to leverage mobile sensor nodes [72, 73]. The sensor nodes can be moved towards the positions that have poor coverage or towards the disconnected areas. Mobile sensor networks are very useful in situations where deterministic deployment mechanisms fail or not suitable, for example, a hostile environment where sensors cannot be manually deployed or air-dropped [22]. Due to the limited energy capacity, sensing range and communication range, the sensor nodes need to be well planned to organize themselves into a multi-hop network. After the initial random deployment, these mobile sensors self-deploy to achieve an improved coverage over the ROI. Wireless sensor networks need to meet these requirements of coverage and connectivity. To ensure the connectivity, the sensors need to be placed close enough to each other so that they are within the communication range. On the other hand, in order to maximize the coverage, the sensors need to be placed not too close to each other so that the sensing capability of the network is fully utilized and at the same time not too far from each other to prevent formation of coverage holes. In random distribution of sensor nodes, more deployed sensor nodes will result in a better coverage of ROI but this is very costly. Thus, the sensor nodes optimization is needed to minimize the number of nodes in order to reduce the network cost in the terms of coverage and connectivity [74]. There are different strategies that can be used for optimizing the coverage in WSN which are categorized into four groups: force based [30, 32, 34, 74, 75], grid based [30], computational geometry [30, 58] or hybrid technique [35, 37, 58, 76]. Figure 2.8 summarized the approach used in each of the coverage strategy.

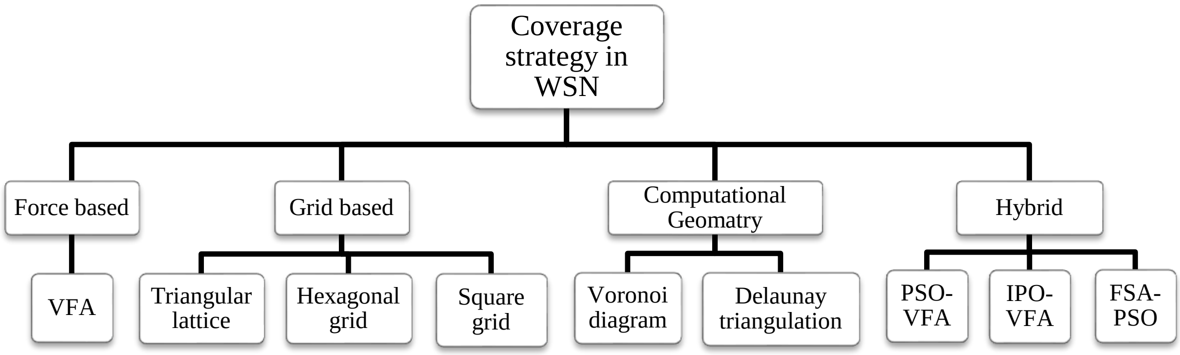


Figure 2.8: Coverage Strategy in WSN

Force based deployment strategies rely on the sensors mobility. The sensor nodes are forced to move away or towards each other using virtual repulsive and attractive forces to achieve a full coverage. The sensor nodes will keep moving until equilibrium state is achieved where repulsive and attractive forces are equal thus they end up cancelling each other. Virtual force-based approach is a popular approach for node deployment. In virtual force-based approach, the sensor nodes, the obstacles and the preferential areas are modelled as points subject to attractive or repulsive force among them. By setting a threshold of the desired distances between sensors, each sensor moves in accordance with the summation of the force vectors and eventually a uniform deployment is achieved [36].

Grid based strategy divides the target field into grids. Grid points are used to measure coverage and to determine sensors positions in WSN deployment. Grid points can also be used in predetermine deployment method. There are three types of grids commonly used in networking i.e. triangular lattice, square grid and hexagonal grid. The coverage is measured as the ratio of grid points covered to total number of grid points in the ROI [31]. The accuracy of the estimation is determined by the size of each grid. The smaller the size of grid the more accurate the estimation is. According to [77], grid-based sensor networks divides the ROI into square grids and the sensors can only be placed at the centre of the square. The size of grid depends on how dense the WSN environment is.

Computational geometry is frequently used in WSN coverage optimization. The most commonly used computational geometry approach are Voronoi diagram and Delaunay triangulation [30]. Wang et al. [55] used Voronoi diagram in enhancing WSN coverage using sensor nodes mobility. The Voronoi diagram of the network is constructed based on the sensor nodes positions. Using the Voronoi diagram, decision can be made if the sensor nodes need to be repositioned or to stay. The protocols of VECtor-based algorithm (VEC), VORonoi-based algorithm (VOR) and Minimax algorithm are suggested in [55] started with the initial random deployment of the sensor nodes. According to VECtor-based algorithm (VEC), a sensor node that fully covers its Voronoi polygon will exert expulsion force to push its neighbor away to improve the coverage area. The proposed VORonoi-based algorithm (VOR) is used to cover the coverage holes by moving the sensor nodes towards its local maximum holes which is located at its farthest Voronoi vertex. In the last algorithm, Minimax algorithm is used to reduce the coverage hole by moving the sensor nodes towards the farthest Voronoi vertex but not as far as VOR algorithm. The Voronoi diagram and Delaunay triangulation are used to estimate the worst and best case for coverage calculation [78]. This work focuses in finding the maximum breach path (worst case coverage) and maximum support path (best case coverage). The work proved that a maximum breach path must lie on the edges of Voronoi diagram while maximum support path with a highest coverage lie on the edges of Delaunay triangulation. The approaches can be used in incremental deployment in order to improve the coverage with the best place deployment of additional sensor nodes. The worst and best case coverage control algorithm were also used in [79]. The authors described a model of coverage issues and designed the coverage control algorithm based on the Voronoi diagram and Delaunay triangulation. Delaunay triangulation is also used in [80] which focused on how to add additional sensor nodes after an initial random deployment to increase the coverage area. [81] have proposed a new measurement scheme based on Delaunay triangulation. The scheme gives detailed information about the areas and distance between sensor nodes. Fat, healthy and thin sensor nodes were used to show the dense, optimal and scattered areas. However, the computational geometry approaches are complicated where the methods are controlled by the number of sensor nodes (sites) and the algorithm used [30].

In force based deployment strategy, by placing a threshold of the desired distance between sensor nodes, each sensor node move in accordance with the summation of the force vectors and eventually a uniform deployment is achieved. Different from the computational geometry approach, virtual force driven algorithm do not move sensor to a predefined position in some grids or polygon but relies on the interaction between the sensor nodes [82]. Therefore, this thesis used the force based approach to relocate the sensor nodes in order to overcome and minimize the coverage and connectivity problems such as coverage hole, overlapping and connectivity failure.

The goal of an optimal sensor deployment strategy is to have a globally connected network while optimizing coverage at the same time.

2.6.1 Virtual Force Algorithm

Virtual Force Algorithm (VFA) uses a force-directed approach to achieve a redeployment of sensor nodes after an initial random deployment [32, 33, 75]. In the VFA, each sensor node behaves as a source of force for all other sensor nodes within its communication range. The VFA approach will exert force between the nodes either by attractive or repulsive force. When two nodes are close enough, the force is in repulsive force which intent to separate them but when two nodes are far from each other, the force become attractive which draws them closer [74]. The repulsive force can minimize the redundant coverage or overlapping while the attractive force can eliminate the coverage holes. The force exerted on node *i* by node *j* in the network (denoted by $F_{i,j}$) as the equation below:

$$\overrightarrow{F_{i,j}} = \begin{cases} W_a\left(D_{i,j} - D_{th}\right)\alpha_{i,j} & if\ D_{i,j} > D_{th} \\ 0 & if\ D_{i,j} = D_{th} \\ W_r D_{i,j}, \alpha_{i,j} + \pi & if\ D_{i,j} < D_{th} \end{cases} \tag{2.4}$$

where $D_{i,j}$ is the Euclidean distance between sensor node *i* and *j*, D_{th} is the threshold on the distance between *i* and *j*, $\alpha_{i,j}$ is the orientation (angle) of a line segment from *i* and *j*. W_a and W_r represented the measures of attractive and repulsive forces. Figure 2.9 illustrates how VFA algorithm is used for sensor deployment.

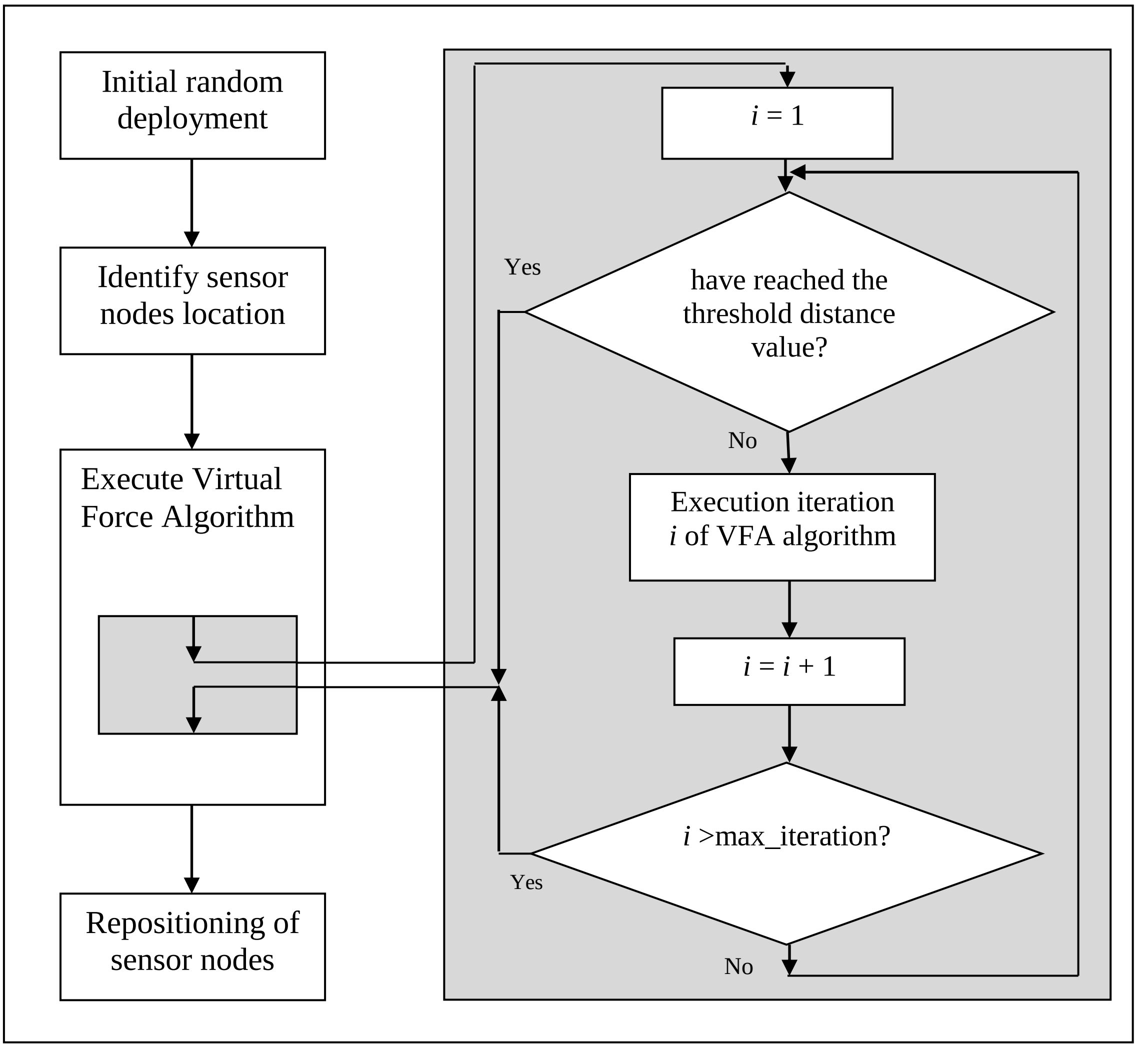


Figure 2.9: Sensor Deployment with Virtual Force Algorithm

The coverage provided by a random deployment can be improved using a force-directed algorithm. Zou and Chakrabarty [32] proposed VFA as a sensor deployment strategy after an initial random deployment of sensor nodes and the VFA algorithm attempts to maximize the sensor field coverage. They also proposed the VFA as a sensor deployment strategy to enhance the coverage after an initial random placement of sensor nodes in [33]. Garetto et al. [83] proposed a scheme based on virtual forces, which allow nodes to coordinate their movements without the need of any central controller distributed algorithm for self-deployment and event-based relocation in mobile networks.

Chen et al. [74] studied on the deficiencies of the VFA. The authors found that the original VFA encounter the problem of effective distance of acting force and useless motion. Two effective improvement of VFA have been proposed; Improved VFA and Exponential VFA to improve the original VFA algorithm by setting the maximum boundary coordinates, introducing the effective communication distance and constraining maximum step size. Most of the researchers used the VFA strategy to solve only the coverage problem which is to overcome the coverage hole and overlapping problem but the connectivity problem is not considered in the original VFA. Yang et al. [84] used a Virtual Force based Deployment-Enhanced Algorithm (VFDEA) as a hybrid technique to avoid overlapping, coverage holes and partition. Li et al. [34] has proposed an Extended Virtual Force-Based (EVFA) approach in order to overcome the problem of connectivity in the original VFA. The simulation result from the Extended Virtual Force-Based approach shows a better performance in coverage rate, distance uniformity, and connectivity uniformity than the earlier VFA. Summary of VFA approach from the researchers are listed in Table 2.2.

Table 2.2: Summary of VFA Based Approach

Technique	**Description**	**Authors**
Virtual Force Algorithm (VFA)	• VFA is used in four performance criteria namely: i) coverage ii) connectivity iii) energy consumption iv) fault tolerance	[75]
	• proposed a VFA as a sensor deployment strategy after an initial random placement of sensors and the VFA algorithm attempts to maximize the sensor field coverage.	[32]
	• based on virtual forces, which allow nodes to coordinate their movements without the need of any central controller. • distributed algorithm for self-deployment and	[83]

	event-based relocation in mobile networks	
Improved VFA and Exponential VFA	• studied the deficiencies of VFA and the author proposed two effective improvement to improve the original VFA algorithm. i) Improved VFA ii) Exponential VFA	[74]
Virtual Force Based Deployment-Enhanced Algorithm (VFDEA)	• used to avoid overlapping, coverage holes and partition.	[84]
Extended Virtual Force-Based Algorithm (EVFA)	• used to overcome the problem connectivity in the original VFA	[34]

Table 2.3 summarizes the techniques used for coverage performance in WSN using the VFA approach.

Table 2.3: VFA Approach for Coverage Performance in WSN

Technique	Description	Reference
Virtual Force Algorithm (VFA)	• VFA attempt to maximize the coverage area	[32, 85]
Virtual Force and Individual Particle Optimization (VFIPO)	• optimize the coverage performance	[35]
Improved VFA and Exponential VFA	• improve the original VFA	[74]

Dirafzoon et al. [35] used the VFA and a hybrid algorithm to attempt a maximize coverage area without consider the requirement of connectivity in a placement of sensor nodes. The Improved VFA and Exponential VFA have improved the original VFA in some extent but there are still not improving a continuous connectivity [74].

Table 2.4 summarizes the VFA approaches that consider the connectivity requirement in WSN. Li et al. [34] have proposed an improvement of force model to overcome a discontinuous connectivity in the original VFA. Yang et al. [84] proposed a VFDEA to obtain better behavior in hybrid sensor deployment that consider the coverage and connectivity problem in the original VFA.

Table 2.4: VFA Approach for Connectivity Requirement in WSN

Technique	Description	Reference
Extended VFA (EVFA)	• Overcome the connectivity problem in the original VFA	[34]
Virtual Force-Based Deployment Enhanced Algorithm (VFDEA)	• The algorithm used to obtain better behavior in hybrid sensor network in term of overlapping, coverage hole and connectivity	[84]

Both techniques assign a threshold distance value in a force model to relocate the position of sensor nodes after the initial deployment. However, the placement of sensor nodes can be optimized based on the threshold distance value that meets the requirement of coverage and connectivity.

To optimize the sensor node deployment in WSNs, this thesis adopts the EVFA to find the optimal node placement. The algorithm considered the connectivity requirement in order to solve the problem of coverage and connectivity in random deployment. The EVFA approach used a equilateral triangle grid (hexagonal placement structure) to implement the ideal deployment pattern. The ideal deployment pattern has a smallest overlapping and no coverage hole exists for a full coverage area in the sensor network [48]. In the ideal deployment, Li et al. [34]

proposed an ideal threshold distance, D_{th}, between sensor node and its nearest neighbor as $\sqrt{3}R_s$, where R_s is the sensing range of the sensor node. The sensor nodes relocate to the required placement using a VFA using a repulsive and attractive force. If the position of two sensor nodes are placed closer than the threshold distance, D_{th}, repulsive forces are exerted. Attractive forces are exerted if the position of two sensor nodes are farther apart than the threshold distance, D_{th}, as shown in Figure 2.10. The distance between node 1 and node 4 in Figure 2.10(a) is more than threshold distance. $\overrightarrow{F_{14}}$ can be calculated using Equation (2.4) to attract the position sensor nodes. In Figure 2.10(b), the sensor node 5 is located in quadrilateral of sensor nodes 1, 2, 3 and 4, so the exerted force is equal to 0 in this deployment.

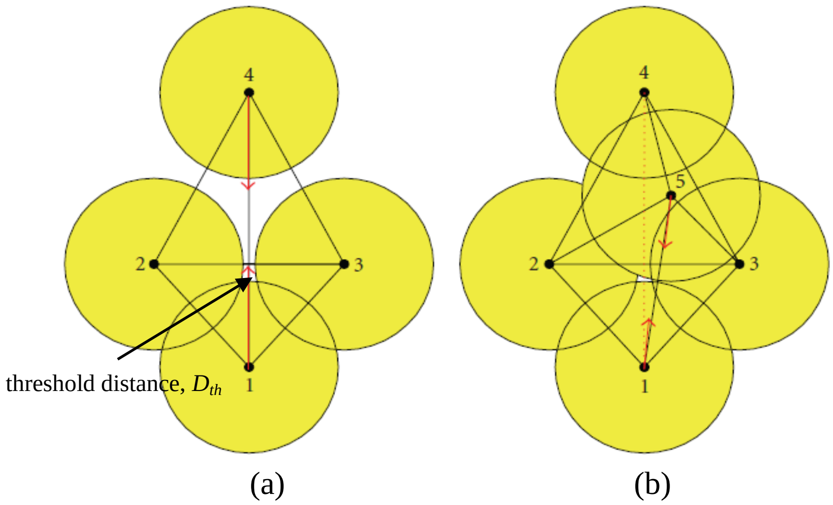


Figure 2.10: Threshold Distance in Extended Virtual Force Algorithm

2.6.2 Hybrid Coverage Strategy

Hybrid technique in node placement has been used to improve the coverage performance in WSN applications. Some authors adapted the VFA with the optimization algorithm as a hybrid technique in node placement algorithm. Song et al. [43] used a hybrid technique called modified Particle Swarm Optimization (PSO) and Virtual Force Algorithm (VFA) in the proposed algorithm. A modified PSO is proposed to optimize the node density and the VFA is used to adjust the position of mobile node according to the QoS. Difarzoon et al. [35] used a combination of VFA and Individual Particle Optimization (IPO) as a novel hybrid deployment algorithm called VFIPO for deployment optimization problem of sensing networks. In the proposed algorithm, the searching of optimal deployment vectors is adopted from the IPO approach, while the VFA is used to direct the relocation of individual particle towards the better positions. In this novel algorithm, the effective coverage of the sensing nodes is considered as the fitness function of deployment which is influence by the positions and probabilistic detection range. Both algorithms adapted the original VFA algorithm to relocate the position of sensor nodes in order to optimize the coverage performance in the hybrid algorithm.

There are other hybrid techniques in node placement based on optimization algorithm; Fish Swarm Algorithm (FSA) and Particle Swarm Optimization (PSO) proposed by [37]. The algorithm is able to relocate the redundant sensor nodes to recover the coverage hole area and improved the performance of coverage area using a mobility of sensor nodes. The authors compared the performance of hybrid algorithm with a standard FSA and PSO. The simulation results show that the coverage ratio using hybrid algorithm is higher compared to FSA and PSO. However, the hybrid algorithm proposed by the authors only considered the placement of sensor nodes for coverage performance. The connectivity is also a main issue in WSN that need to emphasis in the node placement algorithm. Both coverage and connectivity criteria is important in node placement algorithm in order to perform the quality and operation in WSN applications. Table 2.5 shows the summary of hybrid approach used in node placement.

Table 2.5: Summary of Hybrid Approach in Node Placement

Technique	Description	Authors
Modified PSO and VFA	• To optimize the node density and to adjust the position of mobile node according to the QoS	[43]
Virtual Force Based Individual Particle Optimization (VFIPO)	• The IPO approach is adopted to implement the searching of optimal deployment vectors while virtual force algorithm is used to direct the relocation of individual particles towards the better positions.	[35]
Hybrid algorithm based on the FSO and PSO	• The hybrid algorithm can effectively optimize the nodes deployment of the sensor networks to improve the coverage of the whole networks	[37]

2.7 Metaheuristic Optimization Technique

Metaheuristic optimization deals with optimization problems using metaheuristic algorithm. Optimization is essential in different perspective including engineering design, economics and Internet routing. An optimization can be defined as solution for a minimization or maximization problem. The efficient search or optimization algorithms are used to solve the optimization problems [86]. There are many optimization algorithms which can be classified in many ways, depending on the focus and characteristics. Metaheuristic algorithms are often nature-inspired, and they are becoming very powerful in solving global optimization problems [87]. Modern metaheuristic algorithms inspired by nature are emerging and they become increasingly popular because the algorithms intend to search around the current best solutions and select the best candidates or solutions and makes sure the algorithm can explore the search space efficiently [86, 88].

2.7.1 Optimization Technique in Node Placement

There are some popular metaheuristic algorithms for optimization such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), and Cuckoo Search(CS) [88]. A number of optimization techniques have been implemented in WSN node placement such as PSO [58, 89-92], ACO [85, 91] and GA [93-96]. Due to GA's failure in optimal placement in employing a large number of sensor node, Tripathi et al. [95] have proposed a hybrid Genetic Programming (GP) and Genetic Algorithm (GA) for solving the problem in traditional GA. The node placement was found to be better than random placement strategy in the GA placement strategy. A novel approach for maximum coverage area proposed by [94] used a Voronoi diagram to divide the region of interest into cells. GA is then used to find best position for additional mobile nodes to heal the coverage holes. Zou et al. [85] proposed an energy efficient coverage control algorithm with a minimum number of sensor nodes with a less energy consumption. The coverage holes are very important in WSN and must be covered to increase the QoS and maximize the coverage area in WSN application. The mobile nodes can move itself to a suitable position by calculating a target location and to minimize the coverage hole problem. The ACO technique is adapted in this algorithm using a static sensor node with a location determination capability to extend the sensor network lifetime. However, as in many WSN applications, sensor nodes are deployed randomly in a large scale area or the inaccessible terrains such as in battlefield or hazardous area. The used of static nodes are not suitable whereby the sensor node cannot relocate itself after the initial deployment and caused the problem of coverage hole and overlapping in a random deployment. Therefore the algorithm should be improved for the implementation in random deployment using static and mobile sensor nodes.

A metaherustic algorithm also been used in WSN for node clustering. Bhondekar et al. [93] developed a node placement algorithm using GA for node clustering with a remaining medium and low transmission range as an active node in sensor node deployment. CS algorithm is used for cluster head selection and formation of clusters among the sensor with a combination of particle approach to achieve energy efficient in WSN [97]. The random walk characteristics via the Levy flights in a CS algorithm give more efficiency in exploring the search space for optimal searching. Thus, this thesis proposed a CS optimization technique to search an optimal threshold distance value for optimizing the node placement in WSN based on coverage and connectivity criteria such as node distance, sensing range and communication range. Node placement algorithm using CS algorithm is constructed to find an optimal node placement while maintaining the coverage area and connectivity and to minimize the coverage hole and overlapping between nodes in random deployment.

2.7.2 Cuckoo Search

Cuckoo Search (CS) is one of the latest nature-inspired metaheuristic algorithms, developed by [86, 98] to solve the optimization problem. This algorithm is inspired by the obligate brood parasitism of some cuckoo species by laying their eggs in the nest of other host birds of other species. Cuckoos are fascinating birds because of their aggressive reproduction strategy. Some species named *Ani* and *Guira* lay their eggs in communal nests, though they may remove others' eggs to increase the hatching probability of their own eggs [86, 98]. Quite a number of cuckoos species engage in the mandatory brood parasitism by laying their eggs in the nests of other host birds [98]. The following rules representations that each egg in a nest represents a solution and a cuckoo egg represent a new solution. The strategy is to use the new and potentially better solutions to replace a not so good solution in the nests.

There are three idealized rules used in CS algorithm:

1) Each cuckoo lays one egg at a time and dumps its egg in randomly chosen nest
2) The best nests with high quality eggs will carry over to the next generations
3) The number of available host nests is fixed and egg laid by cuckoo is discovered by the host bird with probability P_α.

Based on these three rules, the basic steps of the CS can be summarized as the pseudo code shown in Figure 2.11.

Cuckoo Search via Levy Flights

```
begin
    Objective function f(x), x = (x1, ..., xd)T
    Generate initial population of n host nests xi (i = 1, 2, ..., n)
    while (t <MaxGeneration) or (stop criterion)
        Get a cuckoo randomly by Levy flights
        evaluate its quality/fitness Fi
        Choose a nest among n (say, j) randomly
        if (Fi >Fj),
            replace j by the new solution;
        end
        A fraction (pa) of worse nests are abandoned and new ones are built;
        Keep the best solutions (or nests with quality solutions);
        Rank the solutions and find the current best
    end while
    Postprocess results and visualization
end
```

Figure 2.11: Pseudo Code of the Cuckoo Search (adopted from [98])

Yang and Deb [98] compared the CS with PSO and GA for various standard test functions and the result from the simulations and comparison show that CS is superior to these existing algorithms for multimodal objective functions. CS is much more efficient compared with GA and PSO [98]. The CS algorithm used a lesser number of parameter and it is potentially more generic to adapt widely in optimization problems. The studies show that CS is very promising and could outperform existing algorithm such as PSO and GA. In comparison with other algorithms, CS performs well for almost all test problems. The mechanism of search move is more stable and balanced compared to the simple mechanism used in PSO [99]. On the other hand, the performance of the algorithmic concepts of the CS, PSO and Artificial Bee Colony (ABC) have been analysed by [100]. The various algorithms have been compared statistically in a numerical optimization of problem solving. Statistical analysis indicates that the problem solving success of the CS are better than the PSO [100]. The CS algorithm generated by Levy flight will speed up the local search with a best solution obtained. Thus, the CS algorithm is chosen as optimization algorithm in this thesis because of the stability and balanced randomization of local search strategy with lesser number of parameter that give the algorithm more efficient and good balance.

A node placement algorithm inspired by the CS algorithm is implemented to find the optimal node placement in order to tackle the problems in random deployment. The method of repulsive and attractive is used to relocate the placement of sensor nodes based on the threshold distance value search by CS in order to maintain the quality of coverage and connectivity. If any coverage hole or overlapping exists, the sensor nodes will calculate the movement to minimize or reduce the size of coverage hole and overlapping.

2.8 Chapter Summary

This chapter focus on the related work in the scope of coverage, connectivity and node placement in wireless sensor network. Coverage and connectivity is the main requirement in order to achieve the quality of service (QoS) in WSN applications. In order to maintain the coverage and connectivity it can be solved by deploying more sensor nodes but its not a practical and reliable option. In the random deployment situation, it may cause the problem of coverage hole and sensing overlapping. Most researchers consider the mobility of sensor nodes as an alternative to overcome the coverage and connectivity problem in random deployment. The sensor nodes placement in WSN environment gives an impact to the coverage and connectivity of the network especially in the random deployment scheme. The force based strategy is used to solve the problem of coverage and connectivity. This strategy used a virtual repulsive and attractive forces method to move away or towards each sensor until it fulfill the coverage and connectivity requirement by minimizing the coverage hole and sensing overlapping. By using the mobile sensor nodes, the position of the sensor can be relocated after the initial random placement in order to improve the network coverage and the connectivity. In addition, the position of the sensor nodes need to be well planned to ensure every sensor node is connected and reach the base station.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

The goal of this thesis is to develop an algorithm for optimal node placement in wireless sensor network that considers the requirements of coverage and connectivity in random deployment. This chapter introduces the methodology used for constructing an algorithm for optimal node placement planning in WSN. This chapter describes the combination of Extended Virtual Force-Based Algorithm (EVFA) with Cuckoo Search (CS) algorithm to find the optimal solution of node placement in order to maximize the coverage area, minimize the coverage hole and overlapping while guaranteeing the connectivity. It consist of four phases namely (i) problem formulation, (ii) design, (iii) testing and validation, and (iv) analysis and evaluation. The experiment and evaluation is conducted using a simulation tool to show the placement of sensor nodes from the algorithm developed in this thesis.

3.2 Problem Formulation Phase

In this phase, the problems of coverage and connectivity in random deployment of wireless sensor network have been analyzed. The coverage and connectivity are the main requirements that are related to the position or placement of the sensor nodes in a wireless sensor network environment. In random deployment, the sensor nodes are randomly deployed in the region of interest where some sensor nodes are deployed far while some are near to each other. Due to random deployment, it causes the problem of coverage hole, overlapping and connectivity failure. This thesis is focused on the coverage and connectivity issues in random deployment that are related to the placement of sensor nodes. The optimal node placement is based on three parameters i.e sensing range, communication range and threshold distance value.

In this thesis, a disk sensing model is used to formulate the coverage and connectivity model. The disk sensing model is also known as omnidirectional coverage model due to its nature. Any point within the disk area is assumed to be sensed by the node. Each sensor node can detect an object or phenomena in a limited range which is called as sensing range, R_s. In homogeneous sensor nodes, the sensing range of nodes is assumed to be the same. Any object within the disk radius or sensing range, R_s, is reliably detected by the sensor nodes.

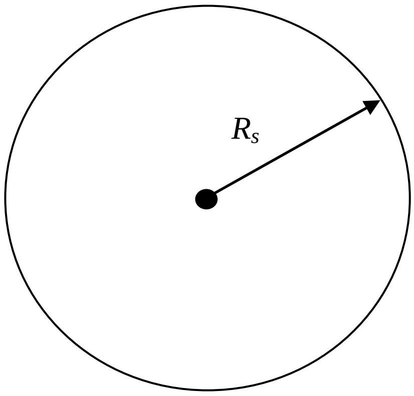


Figure 3.1: A Disk Sensing Model

3.3 Design Phase

The design phase is conducted in a second phase of this thesis. This phase involved the process of constructing the algorithm to find the optimal node placement in order to solve the random deployment problem in the wireless sensor network environment. There are two approaches adopted in conducting the algorithm i.e., Extended Virtual Force-Based Algorithm (EVFA) and Cuckoo Search (CS) algorithm. The EVFA strategy uses a virtual repulsive and attractive forces pattern to move the position of sensor nodes in order to fulfil the coverage and connectivity requirements in sensor deployment. CS algorithm is used to search and select the best solution of threshold distance for minimizing the coverage and connectivity problem in node placement. The combination of this algorithm is used in this thesis to construct a new algorithm. The algorithm is formulated to find the optimal node placement, minimizing the problem in random deployment and guaranteed connectivity based on the best value of threshold distance.

3.3.1 Assumption and Limitation

This thesis is conducted based on the following assumption parameters:

a. Deployment : Sensor nodes are deployed in random deployment scheme over open space area and no obstacle against all nodes.

b. Sensor node : The sensor nodes are dynamic homogeneous identical node in terms of sensing and communication range.

c. Communication : The information from the sensor node to base station is transferred through the multi hop communication

d. Radio range : Sensing range (R_s) and communication range (R_c) is :

$$\boldsymbol{R_c \geq 2R_s}$$

e. Distance : As shown in Figure 3.2, coverage is notified as a point *P* is covered by the sensor node, *v* if their Euclidean distance between node is less than the sensing range of *v*, R_s. $C(v)$ is the sensing circle of the node *v* and boundary of the sensor whose radius is R_s.

f. Sensing model : Disk based sensing model is assumed to have a sensing radius of R_s where the object is within the disk radius, R_s centered is detected by the sensor. As shown in the Figure 3.2, all points within a disk centered at the sensor node are considered to be covered by the sensor. Sensing radius *r* or sensing range (R_s) can be model as a disk with *r* radius. *r* disk cover only those point that fall within it [48].

g. Type of sensor : A mobile sensor node with limited movement and attached to the autonomous robot. Each autonomous robot can turn its moving direction with a limited speed. The autonomous robot is assumed to have an ability to flip up if it is inverse and deployed in the region of 100m x 100m during the initial deployment phase.

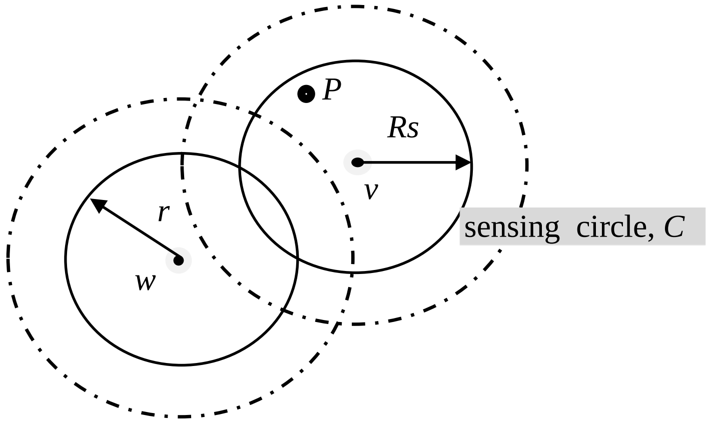


Figure 3.2: Sensing Disk Model

3.4 Testing and Validation

The algorithm constructed in design phase is tested in this phase. An experiment was carried out by simulating the WSN environment with random node deployment. Simulation is an excellent technique to model and evaluate a complex system because real systems are too complex to be developed. Simulation techniques are the most widely used in operations research, management science and network performance evaluation [101]. In the field of communication network system, simulation has emerged as a primary research methodology used by many researchers. Therefore, in this research, simulation will be used to stimulate the random deployment environment.

There are many different possible platforms for network simulation such as ns-2, ns-3, MATLAB, OMNeT++, J-Sim etc. However, matrix laboratory (MATLAB) is selected as the simulation tool in order to test and validate the proposed algorithm. MATLAB is a powerful and multipurpose industry standard simulator used for sensor network simulation, network modeling and complex aerodynamic modeling [102]. MATLAB is a programming environment for algorithm development, data analysis, visualization, and numerical computation. MATLAB also provides several tools such as optimization tool and network design tool that can give more advantages in this research. The algorithm used in this research is not too complicated so MATLAB is chosen as a simulation tool.

The simulation was executed using MATLAB with the dimension of 100m x 100m area of deployment. The total sensor nodes used was N = 25. The sensor nodes are assumed to have a sensing range, R_s = 10m and communication range, R_c = 20m [34]. The sensor nodes were randomly deployed. In each simulation scenario, the sensor nodes are set in different groups. The number of nodes in each group for each simulation scenario varies: 5 nodes, 10 nodes, 15 nodes, 20 nodes and 25 nodes. Simulation for each group of sensor nodes is carried out five times to test the approach's extensibility in a different scenario of random deployment [22]. In a EVFA approach, the threshold distance value was set to $\sqrt{3}\,R_s$. The $\sqrt{3}\,R_s$ value was been used in the proposed algorithm as the initial threshold distance. In CS algorithm and proposed algorithm, the parameter step size = 0.01 is used as a step size of Levy flight. Table 3.1, summarizes the parameters used in the simulations.

Table 3.1(a): Simulation Parameter for Extended Virtual Force-Based Algorithm

Parameter	**Values**
Initial threshold distance, D_{th}	$\sqrt{3}\,R_s$
Sensing range, R_s	10m
Communication range, R_c	20m
Number of nodes, *N*	5-25
Sensor deployment area, *xm* x *ym*	100m x 100m

Table 3.1(b): Simulation Parameter for Cuckoo Search Algorithm

Parameter	**Values**
Initial threshold distance, D_{th}	$\sqrt{3}\,R_s$
Sensing range, R_s	10m
Communication range, R_c	20m
Number of nodes, *N*	5-25
Sensor deployment area, *xm* x *ym*	100m x 100m
Lower bound, L_b, Upper bound, U_b	100, 300
Cuckoo step size	0.01
Maximum iteration	1000

Table 3.1(c): Simulation Parameter for EVFCS Algorithm

Parameter	Values
Initial threshold distance, D_{th}	$\sqrt{3}\, R_s$
Sensing range, R_s	10m
Communication range, R_c	20m
Number of nodes, N	10-25
Sensor deployment area, xm x ym	100m x 100m
Lower bound, L_b, Upper bound, U_b	3.0, 3.5
Cuckoo step size	0.01
Maximum iteration	1000

3.5 Analysis and Evaluation

In this phase, the data from the simulation results are analyzed and evaluated. The parameters in this thesis were used to measure the efficiency of the EVFA, CS and EVFCS algorithm. In the simulation, EVFA relocates the position of sensor nodes using an exerted force pattern. If the distance between sensor nodes is less than threshold distance, $\sqrt{3}\, R_s$, the repulsive force is used to repulse the position of sensor nodes by not more than $\sqrt{3}\, R_s$. Otherwise, the attractive force is used to attract the position of sensor nodes within the optimal distance $\sqrt{3}\, R_s$. In CS algorithm, the initial coverage area is set as the fitness value. This algorithm is used to search for the maximum coverage area and minimum overlapping in random deployment. The performance of the proposed algorithm is compared between (i) EVFA and CS and (ii) EVFA and EVFCS in terms of coverage performance and connectivity.

3.6 Chapter Summary

This chapter focuses on the research methodology used in conducting this thesis. It consists of four phases: analysis, design, testing and validation, and analysis and evaluation. The optimization algorithm is constructed in the second phase which is in design phase. The combination of EVFA and CS algorithm is proposed as an EVFCS algorithm to find the optimal node placement with the best solution of threshold distance to minimize the problem of random deployment in WSN. The testing and validation phase is conducted using a simulation technique. The performance of proposed EVFCS is evaluated with an EVFA algorithm in term of coverage area and connectivity.

CHAPTER FOUR

VIRTUAL FORCE ALGORITHM AND CUCKOO SEARCH ALGORITHM FOR NODE PLACEMENT

4.1 Introduction

This chapter discusses the simulation result and an analysis for the Extended Virtual Force-Based Algorithm (EVFA) and Cuckoo Search (CS) Algorithm for node placement technique in wireless sensor networks. The simulation was conducted using MATLAB where the simulation scenario is based on random deployment with different groups of sensor nodes, each consisting different number of nodes, for both node placement techniques. The sensor nodes were randomly deployed based on the following formula:

$$rand*100 \tag{4.1}$$

in the area of 100 x 100 meter. The formula is differs from the Equation 5.1 to avoid a negative value in the calculation of coverage area in the CS experiment. The negative value will influence the comparison in the experiment between EVFA and CS in term of coverage performance.

The following metrics were used as the performance evaluation of the EVFA and CS algorithm:

i) Coverage area

The coverage area is defined as a covered area in a region of interest. Coverage is usually interpreted as how well a sensor network monitors and covers the area in a region of interest. It can be thought of as a measure of a QoS in various WSN applications.

ii) Connectivity

The connectivity is referred to the probability of sensor nodes in the network which communicate between nodes based on the distance and communication range. Connectivity can be defined as the ability of the sensor nodes to reach the base station within the connected sensor nodes. A network is said to be fully connected if every node can communicate with each other, either directly or via intermediate relay nodes.

4.2 Extended Virtual Force-Based Algorithm

EVFA uses a force-directed approach to achieve a redeployment of sensor network after an initial random deployment [34]. Li et al. [34] proposed a EVFA as a sensor deployment algorithm to maximize the sensor field coverage. Sensor nodes can move towards the required placement using virtual exerted forces. In the EVFA, each sensor node acts as a source of force and exerts either attractive or repulsive forces for all other sensors within its communication range. The repulsive and attractive forces of the sensor nodes depend on a threshold distance, D_{th}. When two nodes are close enough, the force is in repulsive pattern which intends to separate them but when two nodes are far from each other, the force become attractive which draws them closer. The repulsive pattern can avoid the redundant coverage or overlapping while the attractive pattern can avoid the coverage holes. The force exerted on node *i* by node *j* in the network (denoted by F_{ij}) as the equation below:

$$\overrightarrow{F_{i,j}} = \begin{cases} W_a\left(D_{i,j} - D_{th}\right), \alpha_{i,j} & if D_{i,j} > D_{th} \\ 0 & if D_{i,j} = D_{th} \\ W_r D^{-1}{}_{i,j}, \alpha_{i,j} + \pi & if D_{i,j} < D_{th} \end{cases} \tag{4.2}$$

where $D_{i,j}$ is the Euclidean distance between sensor node i and j, D_{th} is the threshold on the distance between i and j, $\alpha_{i,j}$ is the orientation (angle) of a line segment from i and j. Based on [32], virtual forces allow sensor nodes to coordinate their movements without the need of any central controller using a distributed algorithm for self-deployment and event-based relocation in dynamic deployment.

Let any sensor s_i be deployed at point (x_1, x_2). A sensor is defined by R_c for its communication range, and R_s for its sensing range. For any point P at (y_1, y_2), the Euclidean distance between s_i and P define as $d(s_i, P)$, i.e.

$$d(s_i, P) = p(x_1 - y_1)^2 + (x_2 - y_2)^2 \qquad (4.3)$$

The point P is covered by the sensor s_i if $d(s_i, P) \leq R_s$. $c(s_i, P)$ denote the coverage of the point $P(y_1, y_2)$, by the sensor s_i:

$$c(s_i, P) = \begin{cases} 1 & if\ d(s_i, P) \leq R_s \\ 0 & if\ d(s_i, P) > R_s \end{cases} \qquad (4.4)$$

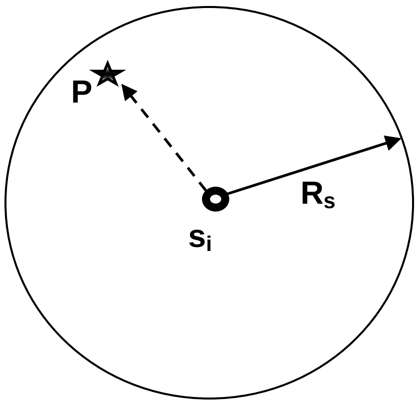


Figure 4.1: Coverage of the Target Point

In Figure 4.1, s_i refers to the sensor node with a sensing range, R_s. A point P is the target point and if $(s_i, P) \leq R_s$, a point P is covered by sensor s_i otherwise the point is not covered by the sensor.

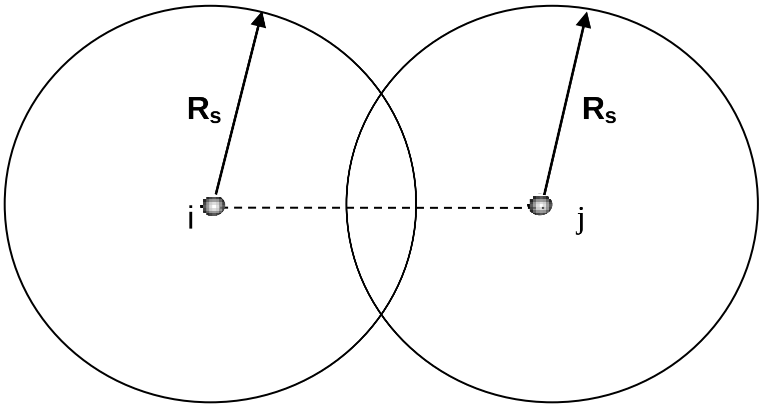


Figure 4.2: Sensing Overlapping

Let the detection region (sensing area) between sensor nodes i (x_1, x_2) and j (y_1, y_2) area overlapped as shown in Figure 4.2. The Euclidian distance between the sensor nodes *i* and *j* defined as:

$$D_{i,j} = (x_1 - y_1)^2 + (x_2 - y_2)^2 \tag{4.5}$$

if $D_{i,j} = (x_1 - y_1)^2 + (x_2 - y_2)^2 \leq D_{th}$ is said as covered and connected between two nodes *i* and *j*.

When $D_{i,j} > D_{th}$ the computation for **attractive** force exerted on *i* by *j* is as follows:

$$FA{\sim}_{i,j} = \left(D_{i,j} - D_{th}\right),\ \alpha_{i,j} \tag{4.6}$$

The maximum distance between nodes needs to be identified so that the sensor nodes will not attract the furthest sensor nodes which results in high energy consumption.

When $D_{i,j} < D_{th}$, the computation for **repulsive** force exerted on *i* by *j* is as follows:

$$FR{\sim}_{i,j} = \left(\frac{1}{D_{i,j}}, \alpha_{i,j} + \pi\right) \tag{4.7}$$

where $D_{i,j}$ is the distance between node *i* and *j* and $FA\sim_{i,j}$ is represented as attractive force and $FR\sim_{i,j}$ is repulsive force. As the result of the forces exerted on *i*, the new location (x'_i, y'_i) of *i* can be expressed as follows:

$$x'_i = x_i + \sim Fx_i \ and \ y'_i = y_i + \sim Fy_i \quad (4.8)$$

The parameters used in this algorithm are listed in Table 4.1.

Table 4.1: Parameter of Extended Virtual Force-Based Algorithm

Parameter	**Description**
N	total number of sensor nodes
R_s	sensing range of sensor nodes
R_c	communication range of sensor nodes
D_{th}	initial value of threshold distance, $\sqrt{3}R_s$
A_{cover}	area covered by the sensor nodes
A_{ovl}	overlapping area
A_{hole}	coverage hole area
$D_{i,j}$	distance between sensor nodes
$F_{i,j}$	exerted on node *i* by node *j* in the network
$FR\sim_{i,j}$	repulsive force
$FA\sim_{i,j}$	attractive force

The algorithm to relocate the sensor nodes using EVFA is shown as in Algorithm 1.

Algorithm 1 : The Extended Virtual Force-Based Algorithm

Step 1. Initialization:
  Identify parameter: N, R_s, R_c, D_{th}, xm, ym
  Generate deployment of sensor nodes randomly
Step 2. Calculation:
  Calculate matrix of relative distance
  Calculate the distance between neighbour

$$D_{i,j} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$$

  Plot the initial distribution on random deployment
  Calculate the overlapping area, *Aovl*
  Calculate the coverage area, *Acover*
  Calculate the coverage hole area, *Ahole*
Step 3. Iteration
  for x=1:1:N

    Calculate matrix of relative distance
    Calculate the distance between neighbour
    Calculate the relative distance from neighbour
    Set initial position of sensor nodes
      for i=1:1:n
        $Fx_1(i) = 0;$
        $Fy_1(i) = 0;$
        Execute virtual force algorithm :
        Condition 1:
        $if\ D_{i,j} > D_{th}$
          $FA\sim_{i,j} = (D_{i,j} - D_{th}),\ \alpha_{i,j}$
        end if
        Condition 2:
        $if\ D_{i,j} < D_{th}$
          $FR\sim_{i,j} = \left(\frac{1}{D_{i,j}}, \alpha_{i,j} + \pi\right)$
        end if
        Condition 3:
        $if\ D_{i,j} = D_{th}$
          $F_{i,j} = 0$
        end if
        Update the new position
        $XR(i) = XR(i) + Fx_1(i);$
        $YR(i) = YR(i) + Fy_1(i);$
      end for
  end for
  Repeat Step 3 until the maximum iteration
Step 4: Plot the final distribution
  Calculate the overlapping area after relocation of sensor nodes, *Aovl*
  Calculate the coverage area after relocation of sensor nodes, *Acover*
  Calculate the coverage hole area after relocation of sensor nodes, *Ahole*

Figure 4.3 shows each sensor node is driven to repulse if there are overlapping area or the position between nodes are placed closer than threshold distance and if the sensor nodes is located far from other sensor nodes, the force become attractive to attract the sensor closer to each other.

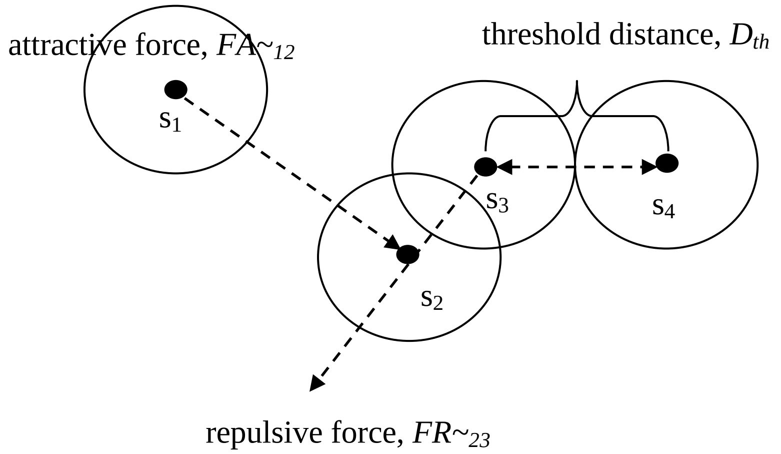


Figure 4.3: Attractive and Repulsive Force in EVFA

When the algorithm terminates, the sensor nodes are relocated based on the threshold distance value ($\sqrt{3}\,R_s$) as shown in Figure 4.4.

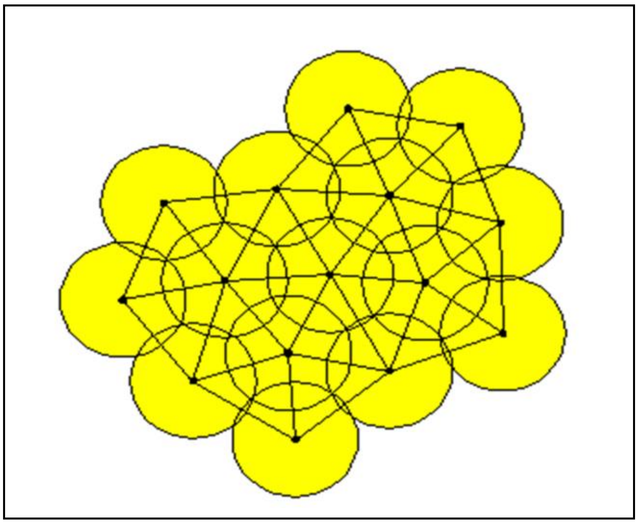
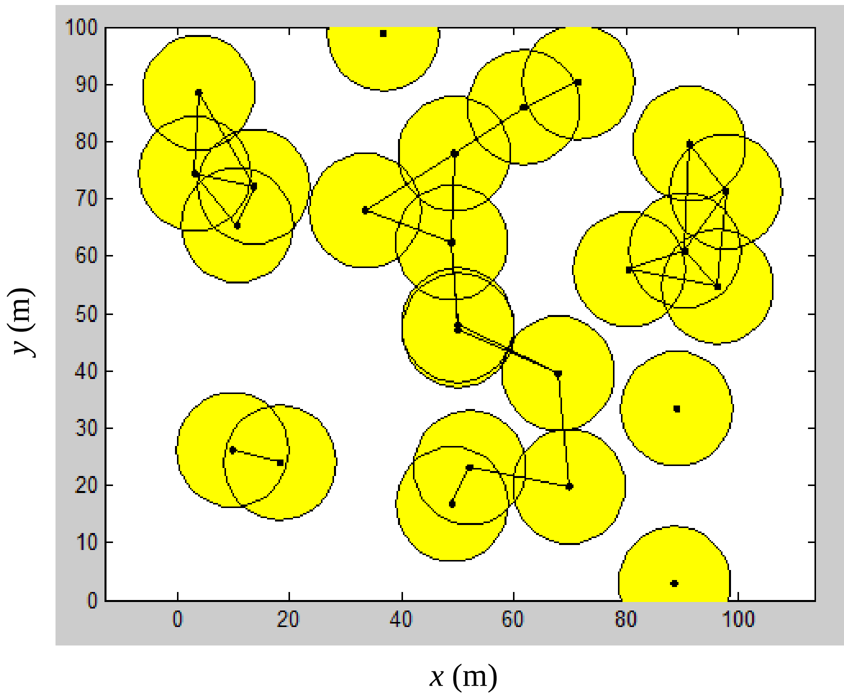
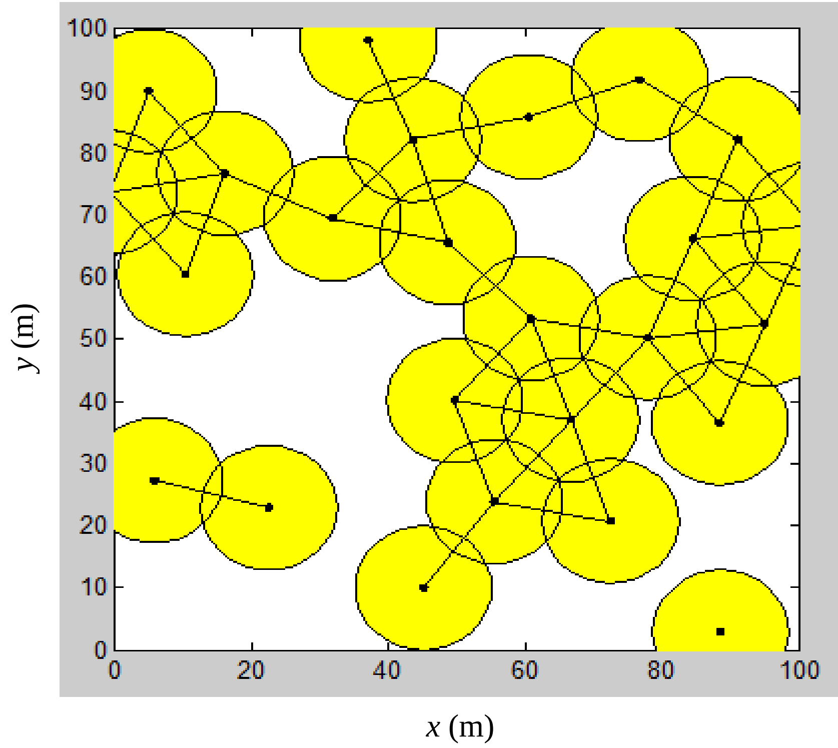


Figure 4.4: Relocation of Sensor Nodes using EVFA

The performance of the EVFA was analysed in terms of coverage area and connectivity after sensor nodes were deployed randomly using a repulsive and attractive pattern. The threshold distance value was set to $\sqrt{3}\,R_s$ where it is assumed as the ideal distance between sensor nodes in the WSN environment [34]. Figure 4.5(a) and Figure 4.5(b) shows the EVFA approach in random deployment using 25 nodes in area of 100m x 100m. Figure 4.5(a) illustrates the initial random deployment and the relocation of sensor nodes is shown in Figure 4.5(b). In EVFA, the metric performance of coverage and connectivity are evaluated using the initial random deployment and performance after the relocation of sensor nodes.



(a) Initial Random Deployment



(b) Relocation using EVFA

Figure 4.5: Node Deployment Scenario using EVFA Approach

4.2.1 Coverage area

The coverage area is defined as on how the region of interest is covered by a number of sensor nodes where the coverage area is related to the sensing performance and measurement of quality services in WSN environment. EVFA approach is proposed to maximize the coverage area and in addition to minimize the coverage hole and overlapping area. The coverage performance in EVFA approach is analysed after the relocation of sensor nodes due to the random deployment. In this thesis, the covered area of each sensor nodes is defined as a disk area with sensing range, R_s. The value of coverage area is defined as

$$C = \frac{\bigcup_{i=1}^{N} Acover_i}{A} \tag{4.9}$$

where $Acover_i$ is the area covered by the sensor nodes *i*, *N* is the total number of sensor nodes, *A* is the total area of region of interest (ROI). Table 4.2 shows the results of coverage area using EVFA approach in 5 replication of simulation runs with a different number of sensor nodes.

Table 4.2: Results of Coverage Area in EVFA Approach

Run	Coverage area (m^2)				
	Number of nodes				
	5	10	15	20	25
1	1325.1	2895.9	4098.2	4870.6	5643.0
2	1386.5	2711.7	4221.0	5054.8	5642.9
3	1325.1	2895.9	3606.9	4256.4	5581.5
4	1386.5	3018.8	3975.4	5054.8	5888.6
5	1448.0	2957.3	3791.1	4440.6	5513.7
Average	1374.2	2895.9	3938.5	4735.4	5653.9

Several number of sensor nodes were considered throughout the simulation to get the average result. The simulation is conducted using various number of sensor node: 5 nodes, 10 nodes, 15 nodes, 20 nodes and 25 nodes. The average of coverage area for each number of sensor nodes is shown in Figure 4.6. The figure shows that the coverage area has increased gradually when the number of sensor nodes were varied from 5 nodes to 25 nodes.

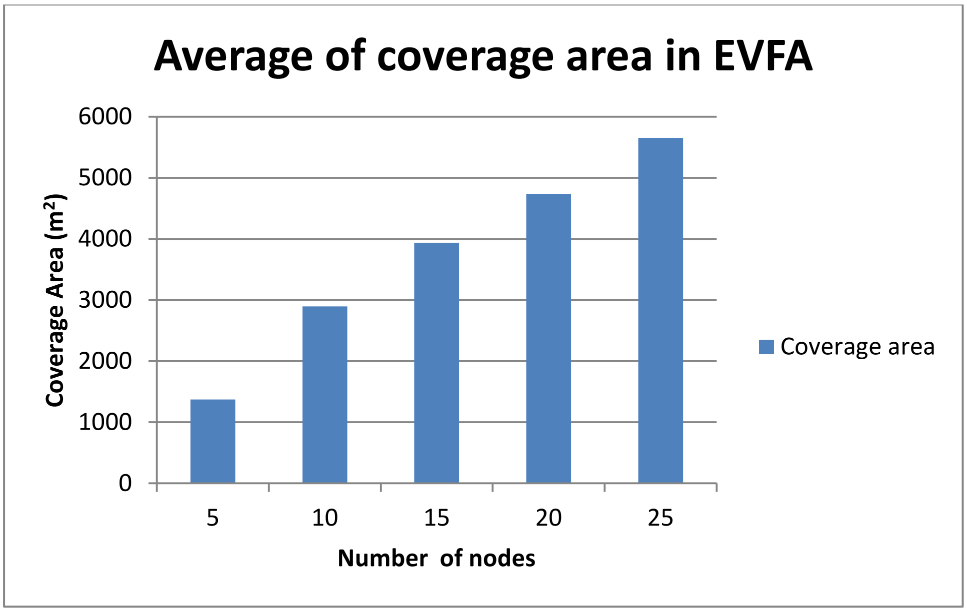
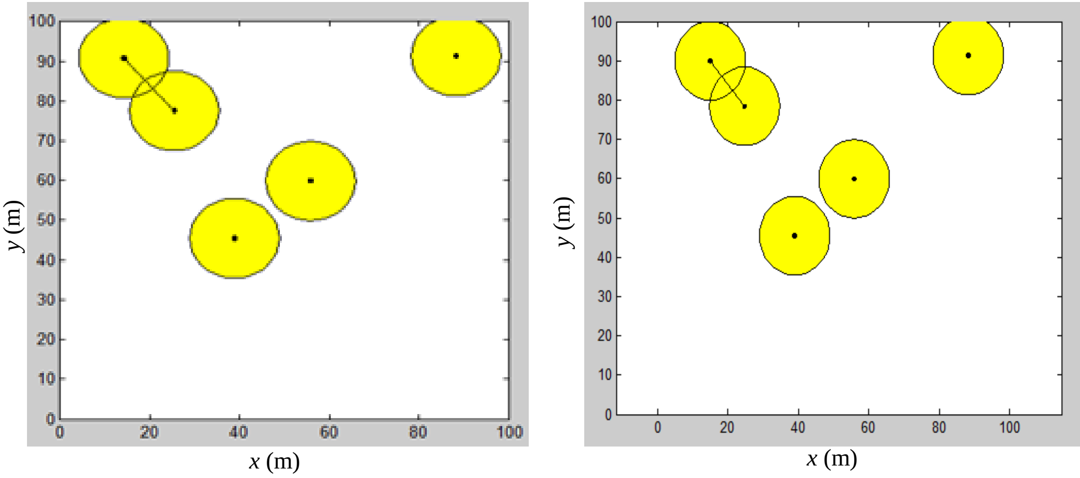


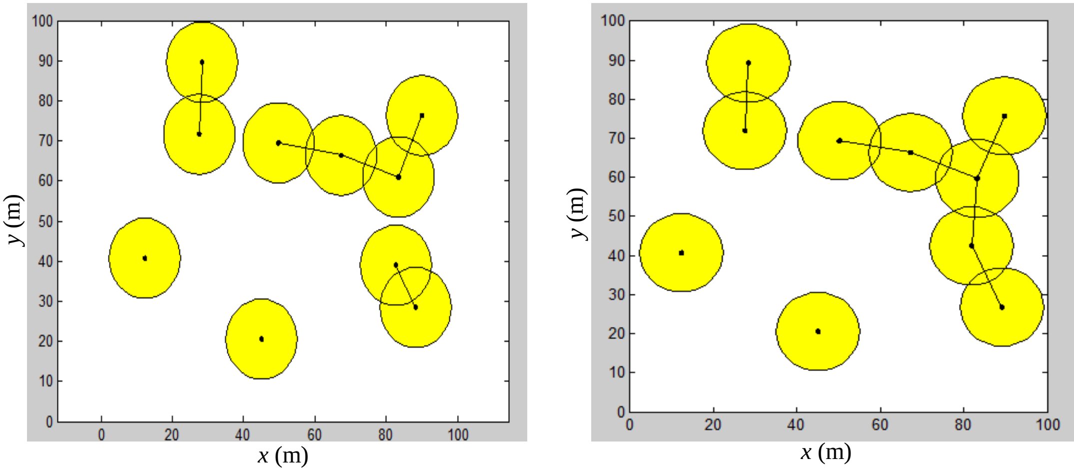
Figure 4.6: Average of Coverage Area in EVFA

In random deployment, it is possible that the overlapping area increases while the coverage hole area is minimized due to the increment number of sensor nodes in the region of interest as depicted in Figure 4.7. Figure 4.7(c) and Figure 4.7(d) show some overlapping areas of sensor nodes. Due to random deployment, it could cause some of the sensors being deployed too close to each other and sensed the same area. In this situation, the sensor nodes were not fully utilized to cover the region of interest. In order to overcome the problem in random deployment, the EVFA approach was implemented to relocate the position of sensor nodes after the initial random deployment. The coverage area can be maximized while the overlapping and coverage hole area were minimized after the relocation of sensor nodes using EVFA.



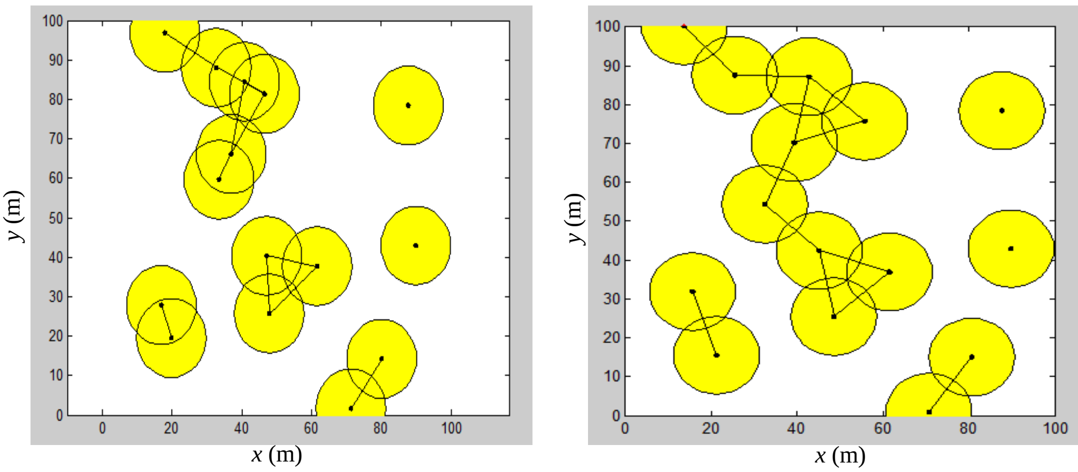
Random Deployment EVFA

a) Random Deployment and EVFA for 5 Nodes



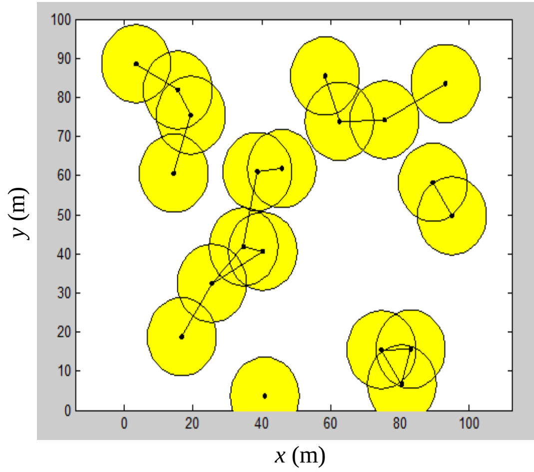
Random Deployment EVFA

b) Random Deployment and EVFA for 10 Nodes

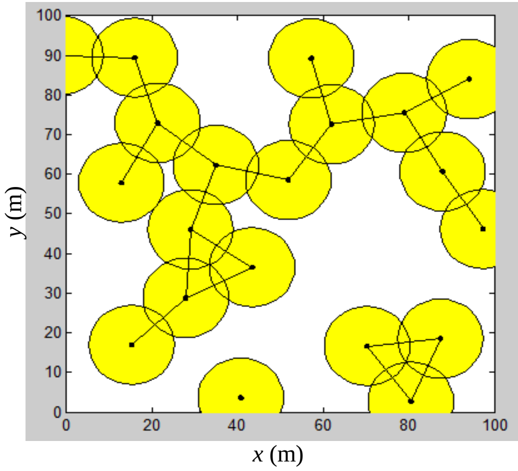


Random Deployment EVFA

c) Random Deployment and EVFA for 15 Nodes

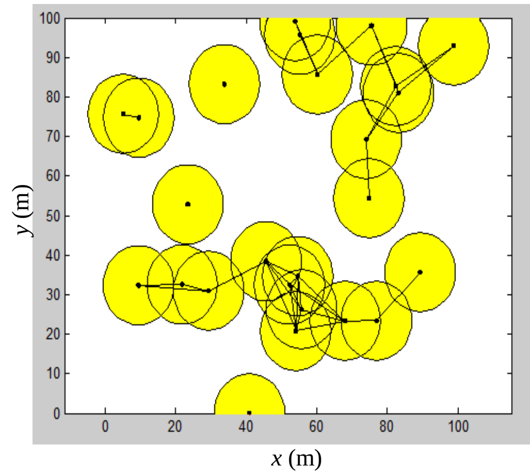


Random Deployment

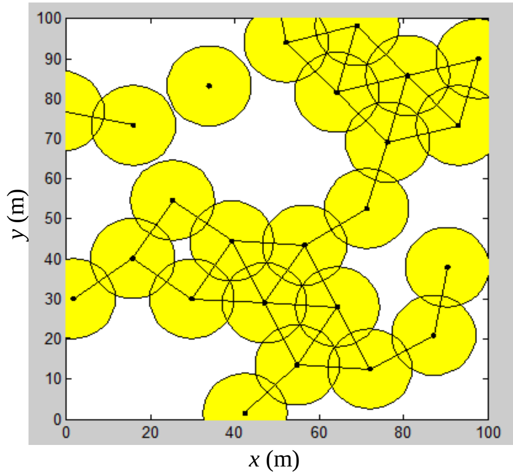


EVFA

d) Random Deployment and EVFA for 20 Nodes



Random Deployment



EVFA

e) Random Deployment and EVFA for 25 Nodes

Figure 4.7: Initial Random Deployment and Relocation of Sensor Nodes using EVFA

Table 4.3(a): Result of Initial Random Deployment and EVFA for 20 Nodes.

Run	Number of nodes					
	20					
	Random deployment			EVFA		
	Coverage Area (m^2)	Overlapping (m^2)	Coverage hole (m^2)	Coverage Area (m^2)	Overlapping (m^2)	Coverage hole (m^2)
1	2347.3	3935.9	7652.7	4870.6	1965.4	5129.4
2	2737.8	3545.4	7262.2	5054.8	1719.7	4945.2
3	3666.4	2616.7	6333.6	4256.4	1351.2	5743.6
4	3686.1	2597.1	6313.9	5054.8	1351.2	4945.2
5	3270.4	1712.8	6729.6	4440.6	1167.0	5559.4

Table 4.3(b): Result of Initial Random Deployment and EVFA for 25 Nodes.

Run	Number of nodes					
	25					
	Random deployment			EVFA		
	Coverage Area (m^2)	Overlapping (m^2)	Coverage hole (m^2)	Coverage Area (m^2)	Overlapping (m^2)	Coverage hole (m^2)
1	3506.7	4347.3	6493.3	5643.0	2219.0	4357.0
2	3714.1	4139.9	6285.9	5642.9	1904.0	4357.1
3	4944.2	2909.8	5055.8	5581.5	2026.8	4418.5
4	3959.6	3894.4	6040.4	5888.6	1965.4	4111.4
5	4433.4	3420.6	5566.6	5513.7	1781.1	4486.3

Table 4.3(a) and Table 4.3(b) show the results of initial random deployment and EVFA approach using 20 and 25 nodes. Both tables show the comparisons of the coverage area, overlapping and coverage hole for initial random deployment and EVFA for five replication of simulation runs. EVFA shows the increment of

coverage area compared to random deployment. For example from the simulation run #1 in Table 4.3(b) the coverage area that was covered by the sensor nodes is $3506.7m^2$ in the initial random deployment. When the EVFA is applied, the coverage area is $5643.0m^2$ where there are 21.36% more areas covered by the sensor nodes. The overlapping area for initial random deployment in simulation run #1 is more than the overlapping area in EVFA. This is due to more intersections of node stacking in initial random deployment compared to EVFA. The overlapping area will give an impact to the coverage area and also the coverage hole area. The simulation result in Table 4.3(a) and Table 4.3(b) show the simultaneous relationship between coverage area, overlapping area and coverage hole area. The coverage hole area will increase due to the higher area of overlapping area but it will give an impact to the decrement of the coverage area. In this situation, the EVFA approach was used to relocate the sensor nodes positions in order to maximize the coverage area while minimizing the overlapping and coverage hole area. The repulsive and attractive force pattern was used in EVFA to repulse and attract the position of nodes depending on the distance between the sensor nodes. When the distance is less than threshold distance, the repulsive force pattern will be used to repel the position of sensor nodes to a new position which is not more than the threshold distance as shown in Figure 4.7. The attractive force pattern was used to attract the position of sensor nodes if the distance between sensor nodes were more than threshold distance and not more than the communication range. After the relocation of sensor nodes, the coverage area improved while the overlapping and coverage hole area were decreased as shown in Table 4.3(a) and Table 4.3(b). Both Table 4.3(a) and Table 4.3(b) proved that the EVFA approach was able to solve the problem of coverage area in random deployment. Furthermore, EVFA also guaranteed that the improvement of the coverage area which will eventually minimize the overlapping and coverage hole as shown in Figure 4.8.

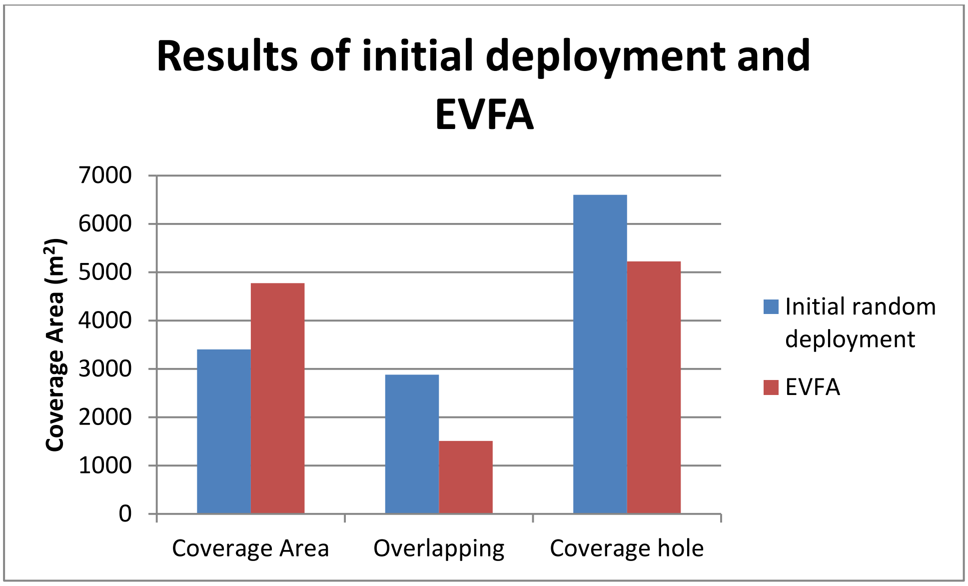


Figure 4.8: Results of Coverage Area, Overlapping and Coverage Hole Area in Initial Random Deployment and EVFA Approach

4.2.2 Connectivity

Figure 4.7 illustrates the initial random deployment and EVFA approach based on 5 10, 15, 20 and 25 nodes deployed in the ROI of 100 x 100 meters. The lines depicted in the simulation results represent the connectivity between a sensor node and its neighbouring nodes. Based on the results presented in Figure 4.7, it can be deduced that random deployment of more nodes led to more overlapping, coverage hole and connectivity intersections. Figure 4.9 shows the intersection of connectivity in the initial deployment using 25 sensor nodes. Figure 4.10 shows the results after applying EVFA to the random deployment where the overlapping and coverage hole area were minimized using the attractive and repulsive forces. Figure 4.10 also shows the improvement of connectivity edge where the connectivity intersection between sensor nodes area were reduced. In certain situation, when the distance between sensor nodes are more than the threshold distance, $\sqrt{3}R_s$, there will be no exerted force needed and will cause the connection to be lost. From the simulation results, implementation of distance force in range of threshold distance and communication range between sensor nodes in EVFA guaranteed the connectivity and prevent it from the node stacking.

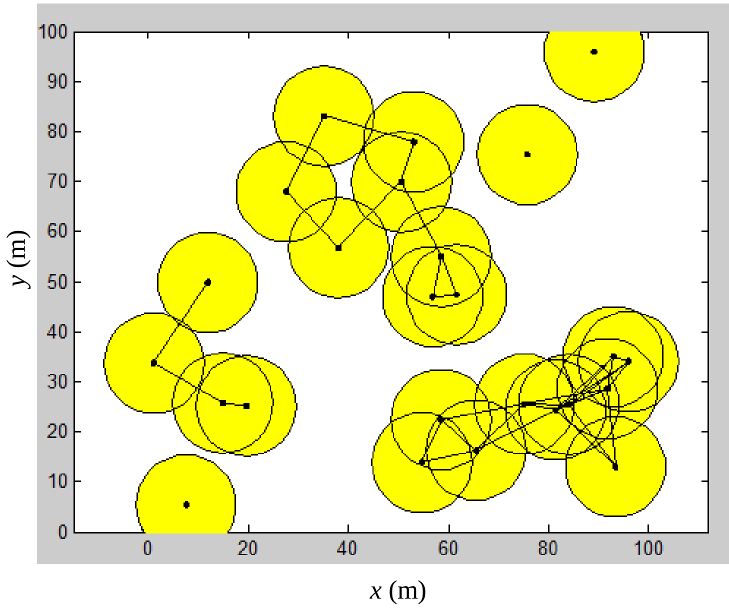


Figure 4.9: Intersection of Connectivity in Random Deployment

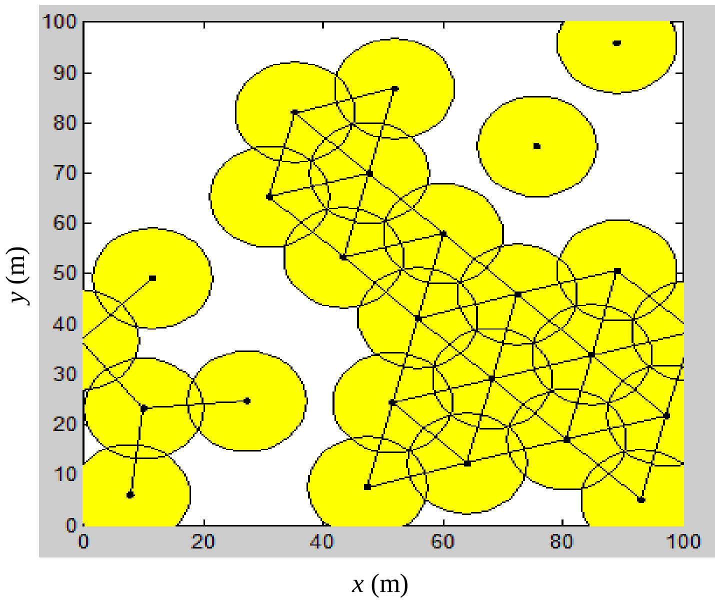


Figure 4.10: Improvement of Connectivity Edge using EVFA Approach

4.3 Cuckoo Search Algorithm

Cuckoo Search (CS) algorithm generated by the Levy flight is used as an optimization algorithm to search a maximum coverage area in random deployment. In this study, the performance of CS algorithm was analysed in terms of coverage area and connectivity. In CS algorithm, the metric performance of coverage and connectivity were evaluated based on random deployment of sensor nodes in a group of sensor nodes for a different number of iteration. In the simulation run, CS algorithm will find the best coverage area for every group number of sensor nodes in different number of iterations.

The rules of CS algorithm in order to search the maximum coverage area in random deployment are as follows:

a) The rule can be interpreted as a set of solution is randomly generated within the range of solutions.

b) The CS algorithm will find the maximum coverage area with a minimum overlapping and compared it with a fitness value.

c) The maximum coverage area and minimum overlapping between nodes is identified and will be abandoned if the rule is not fulfilled.

In this algorithm, an N number of sensor nodes are deployed randomly in xm x ym area. The number of eggs in nests was identified in a range of lower bound, L_b and upper bound, U_b where the range value is set to [100,300]. After the deployment of sensor nodes, the algorithm will calculate the coverage area and set the initial coverage area as a fitness value, F_{it}. The algorithm will find the fitness value for each egg, E_{cov} in N_{est} from the objective function, F_{obj}. In F_{obj}, the sensor nodes are randomly deployed and the coverage area and overlapping area are calculated. The algorithm will randomly generate the new solution using Levy flight within the boundary of L_b and U_b values. A fraction of worst nest, P_a will be removed and replaced by some other nests by constructing new solutions while keeping the best solution, B_{nest}. The new solutions are evaluated in order to find the maximum value of coverage area. The parameters used in this algorithm are described in Table 4.4.

Table 4.4: Parameters used in Cuckoo Search Algorithm

Parameter	Description
N	total number of sensor nodes
N_{est}	number of nests of different solutions
P_a	probability of discovery rate for alien eggs / solution
L_b	lower bound represents lower value of solution
U_b	upper bound represents upper value of solution
E_{dth}	egg represents a potential solution in N_{est}
F_{it}	fitness value
B_{nest}	best solution with $L_b < B_{nest} < U_b$
R_s	sensing range of sensor nodes
R_c	communication range of sensor nodes
D_{th}	initial value of threshold distance, $\sqrt{3}\,R_s$
A_{cover}	area covered by the sensor nodes
A_{ovl}	overlapping area

The algorithm used in CS algorithm to find the maximum value of coverage area is shown as below:

Algorithm 2: Cuckoo Search algorithm (adapted [98])

Step 1. Initialization

Identify parameter: N,N_{est},R_s, R_c, L_b, U_b

Generate the deployment of sensor nodes randomly

Generate initial set of eggs (E_{cov}) in range L_b and U_b set to [100, 300]

Step 2: Calculation

Distance, D using Euclidean distance

$$D_{i,j} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$$

Set initial coverage area = fitness, F_{it}

Step 3. Find the fitness value :

Generate the deployment of sensor nodes randomly

Plot the initial distribution on random deployment

For 1 to total number of N_{est}

Call the objective function

Calculate the overlapping area, *Aovl*

Calculate the coverage area, *Acover*

End For

Find B_{nest}

Step 4. Iteration

For 1 to number of iteration

Generate potential solutions randomly using Levy Flight within L_b and U_b

For1 to total number of N_{est} size

Implement random walk to generate potential of solutions

Call simplebound function

Set the potential solution as a temporary nest

ns_tmp = s;

Apply the lower bound

I= ns_tmp<Lb;

ns_tmp(I) = Lb(I);

Apply the upper bounds

J= ns_tmp>Ub;

ns_tmp(J) = Ub(J);

Update this new move

s= ns_tmp;

End for

Calculate the current fitness, F_{obj}

Remove a fraction of worst nest, P_a and keep best solution, B_{nest}

Sort the fitness and nest value

Sort_fitness_nest = sortrows (fitness_nest)

Remove worst nest (P_a = 0.25 from the number of N_{est})

Remaining a good nest and generate new potential solution

Calculate the new fitness, F_{obj}

Rank the best nest, $B_{nest.}$

End for

Step 5: Result

B_{nest} = best solution of maximum coverage area

When the algorithm terminates, B_{nest} will be the best solution (maximum) of coverage area within the solution range with N number of sensor nodes, R_s and R_c values.

4.3.1 Coverage

The coverage metric performance of the Cuckoo Search algorithm was analysed in terms of maximum coverage area covered by the sensor in the simulation. The covered area was calculated using Equation (4.2). The sensor nodes were deployed randomly using various numbers of sensor nodes: 5, 10, 15, 20 and 25 nodes. The simulation was conducted in a different number of iterations for every group of sensor nodes. Several iterations were considered throughout the simulation to get the average result of the coverage area for a group number of sensor nodes. Table 4.5 and Figure 4.11 show the results of coverage area for a group of sensor nodes in a different number of iteration. The performance of coverage area gradually improved when the numbers of sensor nodes were increased. The coverage area was found to be slightly constant in a group of 5 and 10 sensor nodes from 10 to 1000 iterations as shown in Table 4.5 and illustrated in Figure 4.12 and Figure 4.13. Figure 4.12 shows the constant coverage area is 1570.8m^2 for 10 iterations using 5 nodes. The coverage area gradually increased to 3141.6m^2 when 10 nodes were used in 100 iterations as shown in Figure 4.13. The CS algorithm reached a searching of maximum fitness value of coverage area as depicted in both figures.

Table 4.5: Results of Coverage Area in Cuckoo Search Algorithm

Number of iteration	Coverage area (m^2)				
	Number of nodes				
	5	10	15	20	25
10 iteration	1570.8	3057.4	4288.5	5089.4	5456.9
20 iteration	1570.8	3056.1	4318.5	5216.9	5692.7
50 iteration	1570.8	3108.5	4438.7	5197.6	5800.3
100 iteration	1570.8	3141.6	4485.6	5365.4	5848.0
500 iteration	1570.8	3141.6	4487.8	5497.3	6096.7
1000 iteration	1570.8	3141.6	4556.1	5532.8	6275.4

From Table 4.5, the deployment of 15 to 25 sensor nodes shows that the increment of coverage area is proportional to the increment number of iteration. This result in having more areas covered while the coverage hole areas are minimized when the iteration number is increased between 15 and 25 number of sensor nodes. The maximum coverage area covered in the region of 100 x 100 meter using 25 nodes was 6275.4m^2.

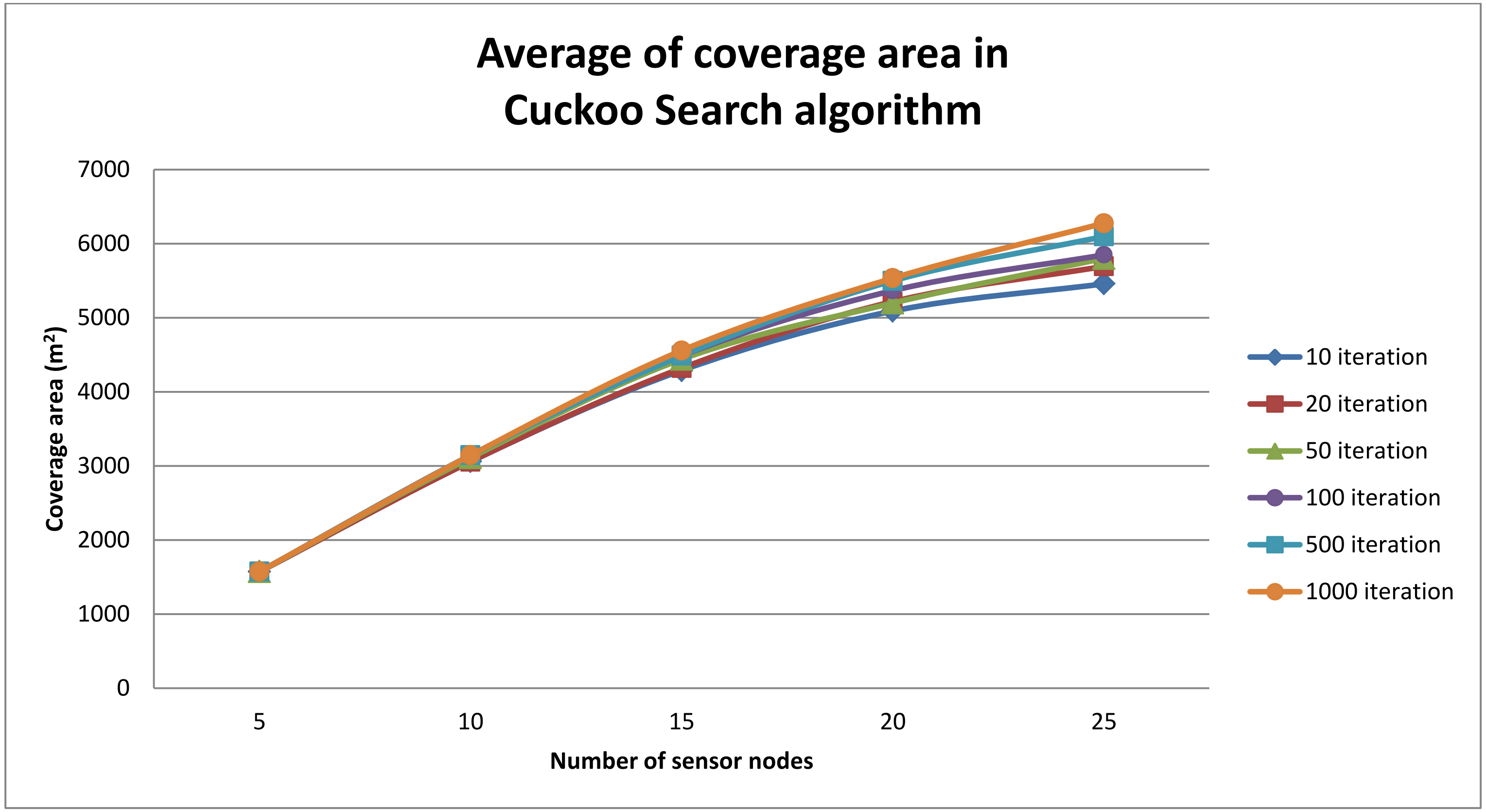


Figure 4.11: Average of Coverage in Cuckoo Search Algorithm

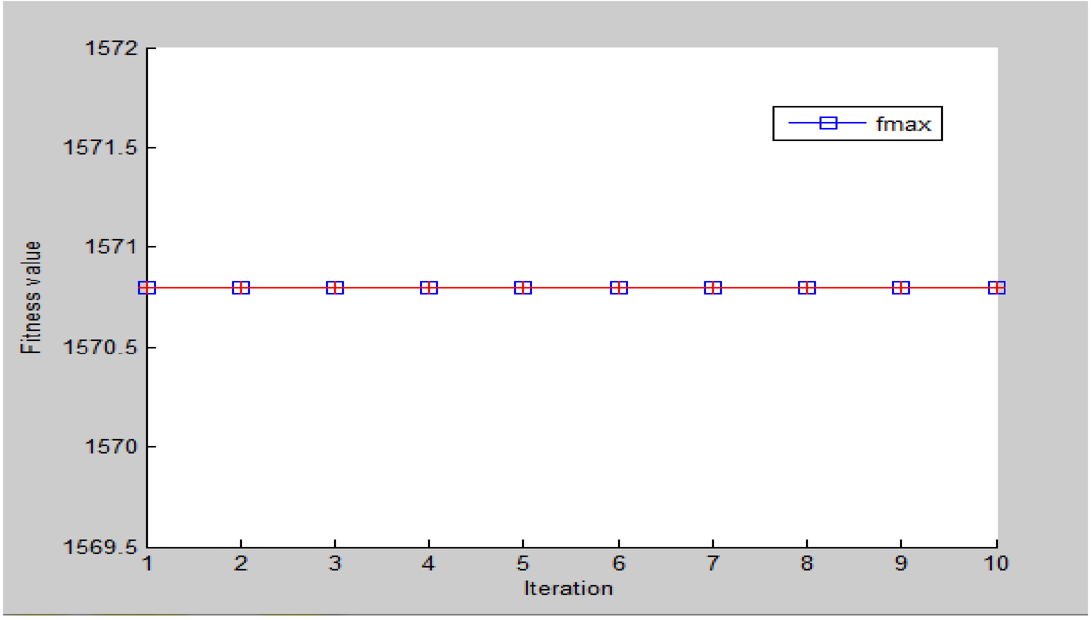


Figure 4.12: Static Coverage Area for 10 Iteration using 5 Nodes

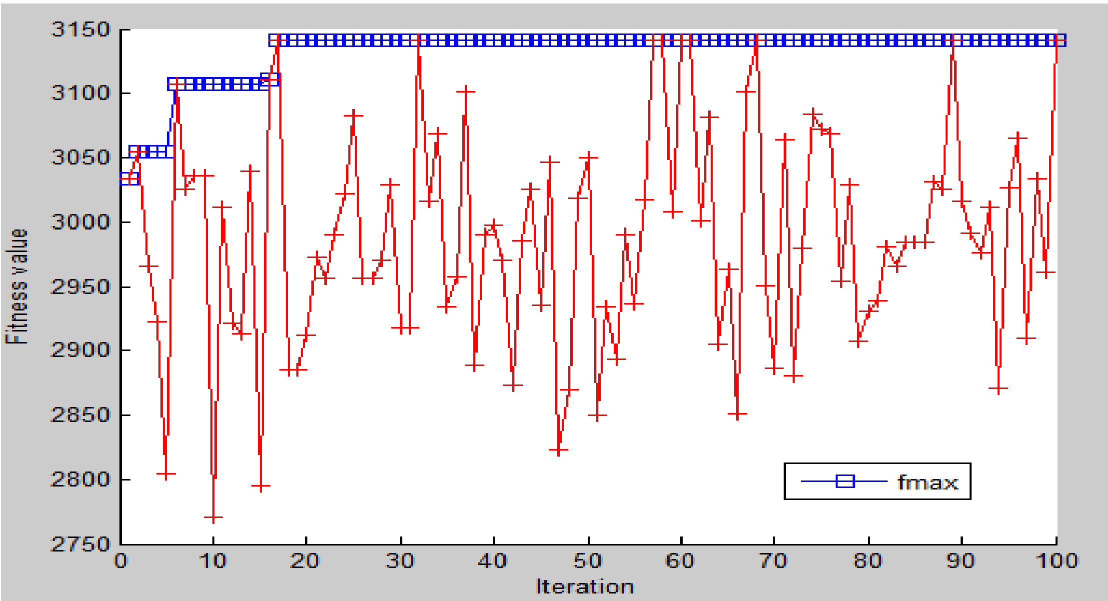
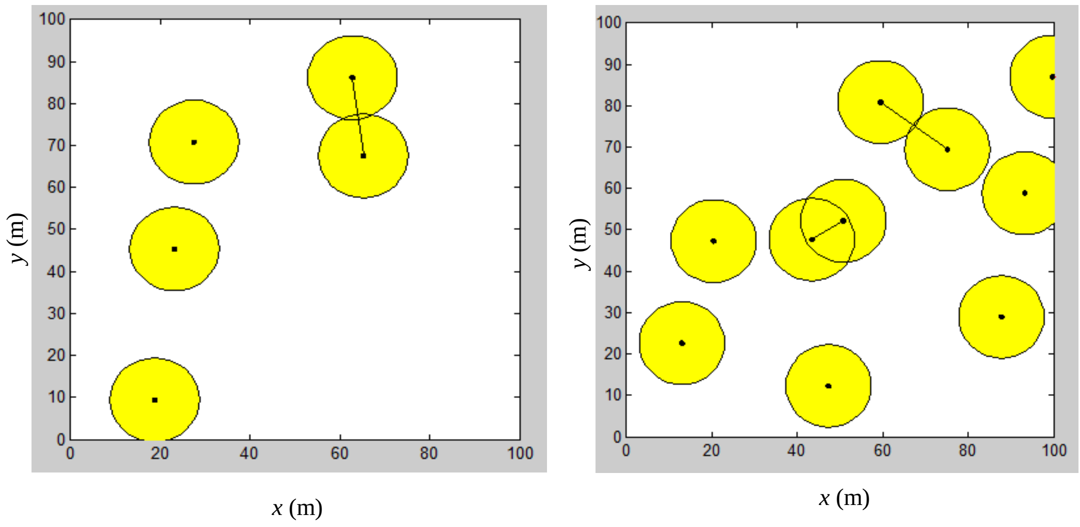


Figure 4.13: Static Coverage Area for 100 Iteration using 5 Nodes

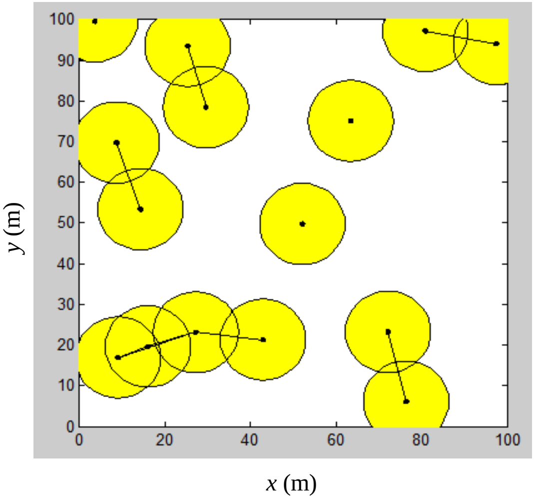
4.3.2 Connectivity

Due to the random deployment of sensor nodes in CS algorithm, the connectivity was not guaranteed due to the coverage hole and overlapping area in the region of interest. Some sensor nodes were deployed far apart or too close to each other. The sensor nodes cannot communicate between each other if the distance between sensor nodes were more than the threshold distance or communication range. In random deployment, some sensor nodes were deployed too close to each other with a possibility of stacking the sensor nodes in a same area. In this situation, there are wastages in terms of sensing areas as well as intersections of connectivity. Figure 4.14 shows the connectivity of 5, 10, 15, 20 and 25 sensor nodes in random deployment using CS algorithm. The lines in Figure 4.14 represent the connectivity between sensor nodes.

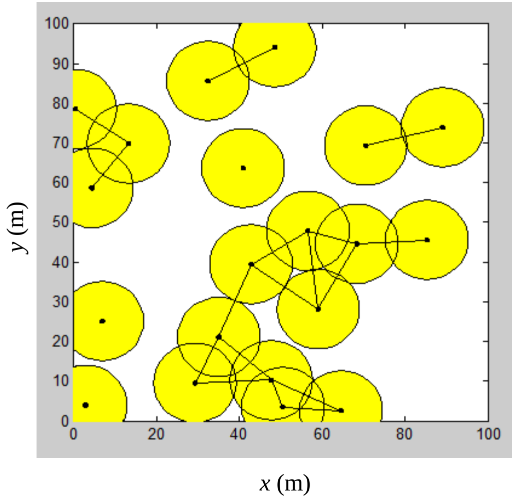


a) 5 Nodes

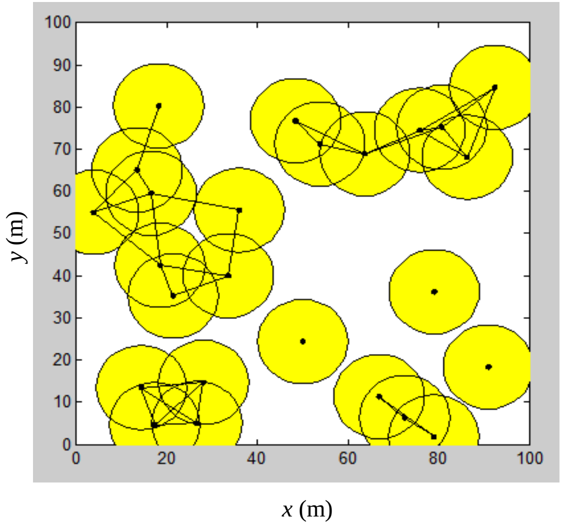
b) 10 Nodes



c) 15 Nodes



d) 20 Nodes



e) 25 Nodes

Figure 4.14: Sensor Nodes Connectivity in Random Deployment

From the simulation runs, it shows that in random deployment, the number of sensor nodes deployed affected the connectivity. As shown in Figure 4.14(a), when 5 sensor nodes were deployed, only 2 nodes were connected to transmit the data while others are disconnected. In Figure 4.14(e), it is shown that more sensor nodes are connected to each other but there still are intersections of connectivity that results in inefficient use of the sensor nodes and overlapping of sensing capabilities.

4.4 Speed

The speed for every simulation run was different between EVFA and CS algorithm. It also depends on the number of sensor nodes deployed and the number of iterations performed. The elapsed times for five replication of simulation runs were recorded in order to show the time taken for node placement using EVFA and CS algorithm.

4.4.1 EVFA

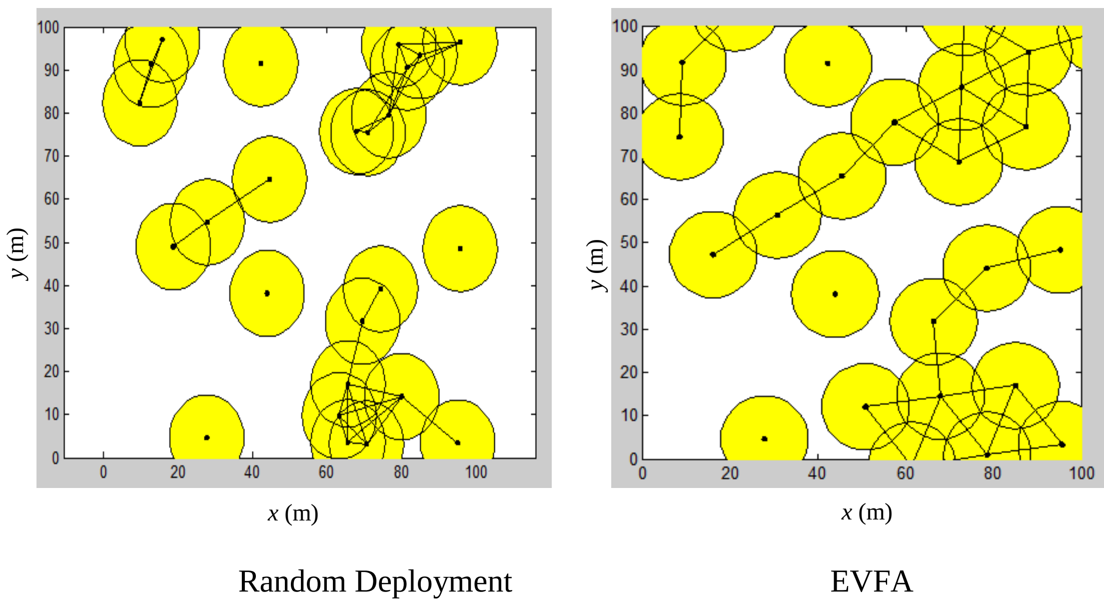
Table 4.6 shows the coverage area and elapsed time in five replication of simulation runs for 5 to 25 nodes in EVFA. The elapsed times are recorded after the relocation of sensor nodes in EVFA. The speed to relocate the sensor nodes increased when 5 to 25 nodes were used. In the simulation run #5 for five sensor nodes, it shows that the elapsed time was 0.9 second to relocate all sensor nodes after the random deployment and the coverage area was $1448.0m^2$. In the simulation run #1 to #4 elapsed time was higher but the coverage area was less than the coverage area in simulation run #5 for five sensor nodes.

Table 4.6: Elapsed Time in EVFA Approach

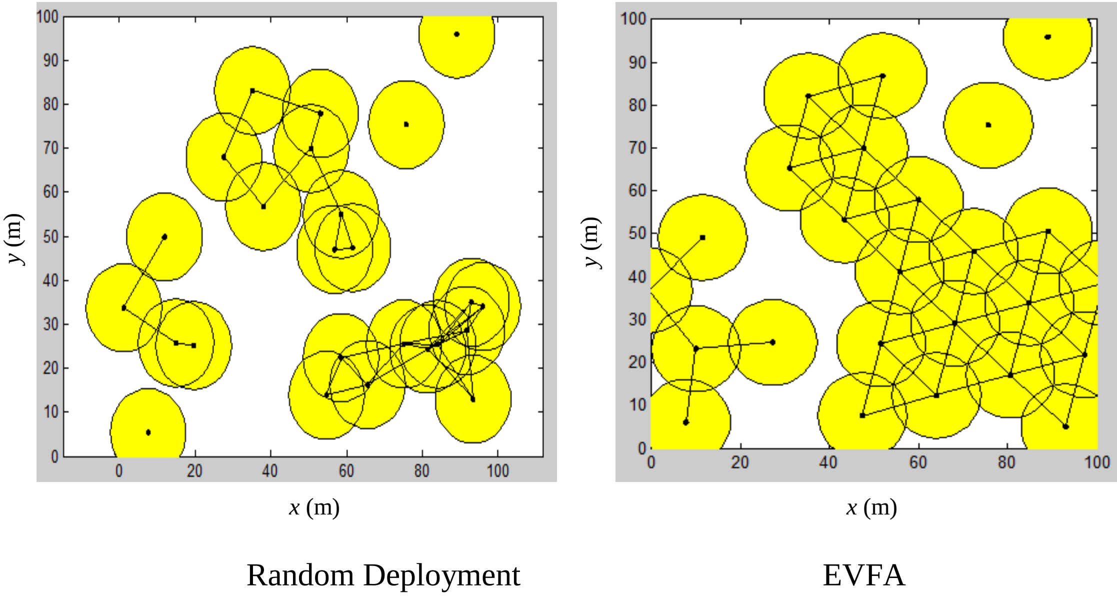
Run	5		10		15		20		25	
	Area (m^2)	time (s)	Area (m^2)	time (s)	Area (m^2)	time (s)	Area (m^2)	time (s)	Area (m^2)	time (s)
1	1325.1	1.0	2895.9	2.2	4098.2	4.8	4870.6	10.3	5643.0	16.9
2	1386.5	1.0	2711.7	2.4	4221.0	4.6	5054.8	9.5	5642.9	16.9
3	1325.1	1.0	2895.9	2.2	3606.9	5.8	4256.4	11.2	5581.5	17.4
4	1386.5	1.0	3018.8	2.1	3975.4	5.1	5054.8	9.5	5888.6	16.4
5	1448.0	0.9	2957.3	2.1	3791.1	5.5	4440.6	10.9	5513.7	17.2

Number of nodes: 5, 10, 15, 20, 25

When there are more overlapping area in random deployment, EVFA need more time to relocate the positions of sensor nodes to achieve the threshold distance between the sensor nodes as shown in Figure 4.15(a) and Figure 4.15(b). The results show that the distance and position of sensor nodes in random deployment consumed more time in EVFA to repulse and attract the position of sensor nodes within the threshold distance value.



a) Elapsed Time: 16.4 second, Coverage Area: 5888.6 m^2



b) Elapsed Time: 17.4 second, Coverage Area: 5581.5m^2

Figure 4.15: Difference of Elapsed Time and Coverage Area using 25 Nodes

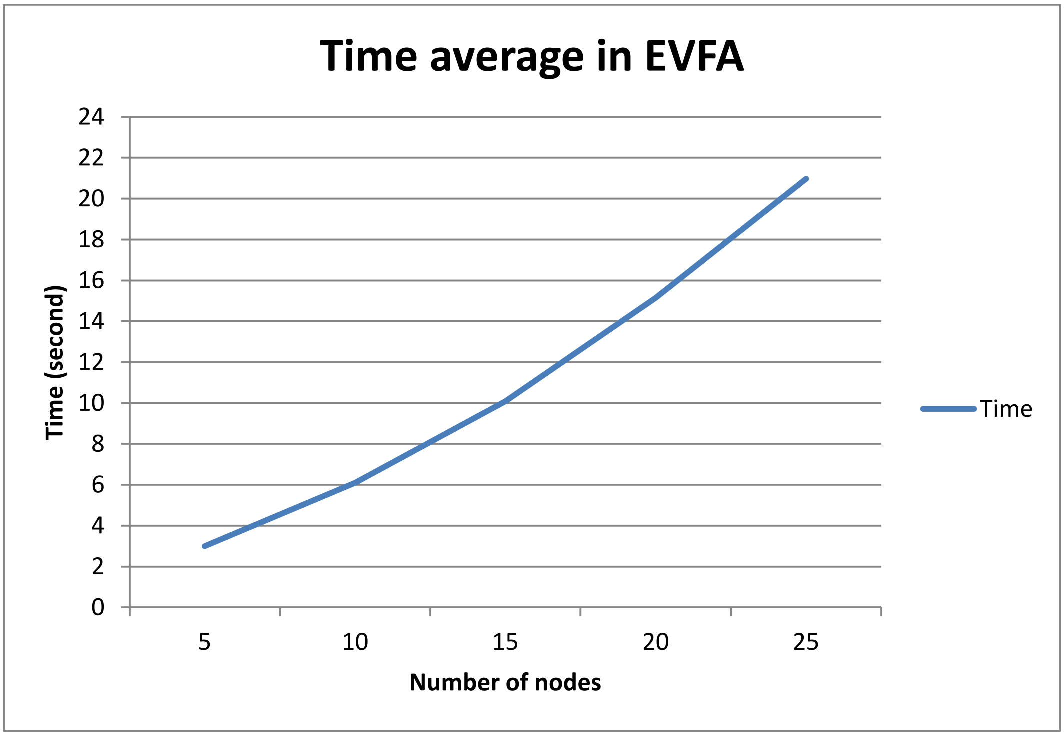


Figure 4.16: Average of Elapsed Time in EVFA Approach

Figure 4.16 shows the average elapsed time consumed for every number of sensor nodes. The time was slightly higher when the number of sensor nodes increased from

5 to 25 nodes. When the number of sensor nodes increased, the EVFA needs to spend more times to randomly deploy and relocate the positions of sensor nodes within the threshold distance value.

4.4.2 Cuckoo Search

For CS algorithm, the time taken to run the simulations were recorded for each iteration. Figure 4.17 shows the average time taken in simulating the CS algorithm for a number of iterations. It can be observed that the time taken for every simulation run were higher due to the increment number of sensor nodes. However, the time taken also depends on the deployment of sensor nodes where more times are needed to relocated if there are more overlapping or coverage hole area arise. The algorithm used a random walk and Levy flight technique in order to find the best coverage area for every step of iteration in the simulation runs. Therefore, the time taken might increase for every number of iteration with the more number of sensor nodes.

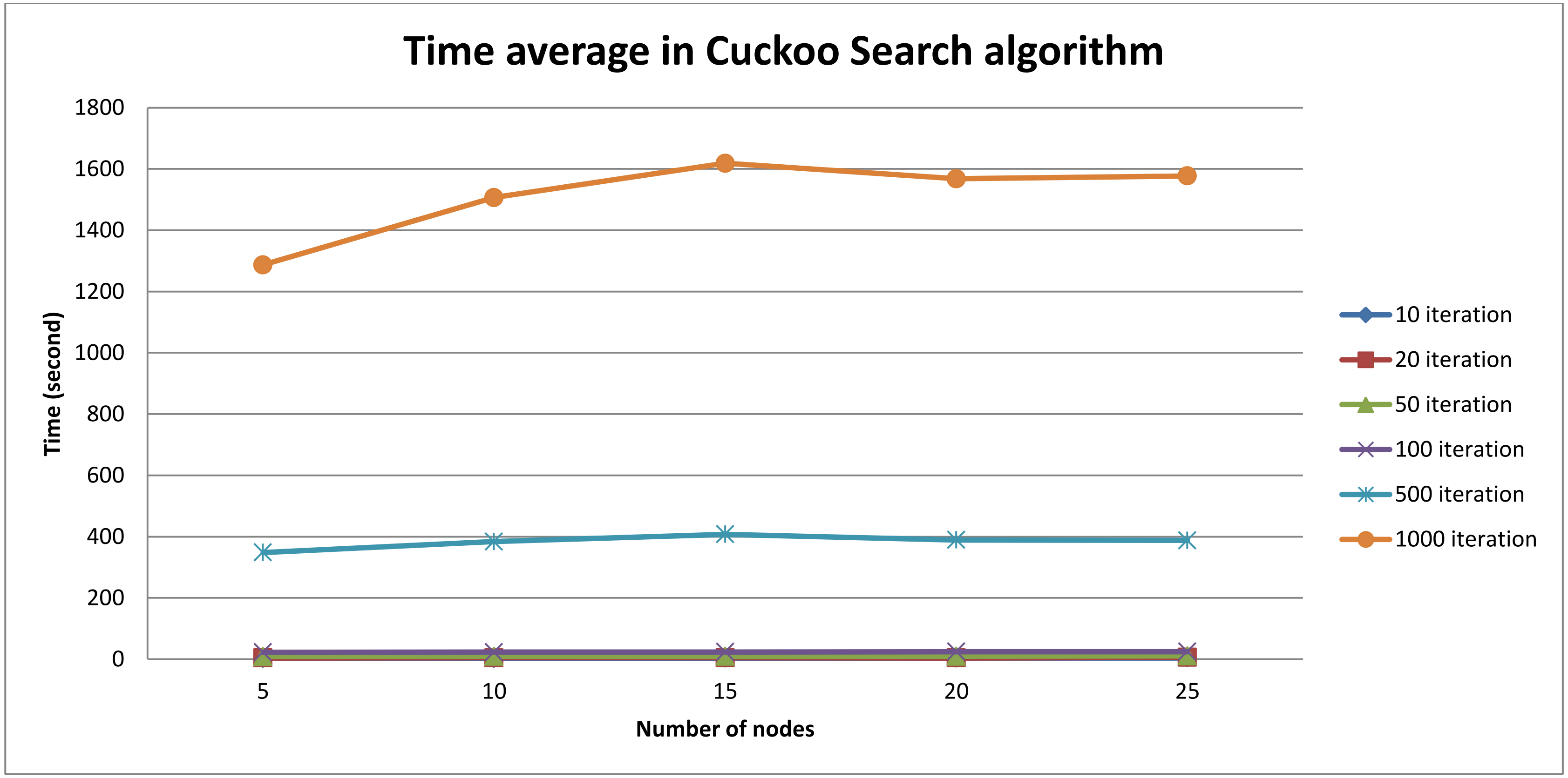


Figure 4.17: Average Time Taken in Cuckoo Search Algorithm

Based on the simulation, the results show that both algorithms have their own strength in improving the coverage performance after the initial random deployment. The EVFA approach can relocate the sensor nodes using a repulsive and attractive force after the initial random deployment. The random deployment may not provide a uniform distribution of sensor nodes and will cause a problem of coverage hole, overlapping and connectivity failure. The repulsive and attractive forces adapted in EVFA approach produced a global uniform distribution of sensor nodes based on the threshold distance value. The simulation results show that the coverage and connectivity problem can be solved using EVFA approach. The coverage area was maximized and the coverage hole and overlapping area were minimized after the relocation of sensor nodes in ROI. The connectivity is guaranteed and the intersection of connectivity is avoided.

The CS algorithm is used to search for a maximum coverage area in random deployment. The algorithm was randomly generated to find a new solution of maximizing the coverage area using a Levy flight within the boundary of lower bound, L_b, and upper bound, U_b, values. In CS algorithm, a fraction of worst nest, P_a, will remove and replace some nests by constructing a new solution while keeping the best solution, B_{nest}. The simulation results obtained were highly accurate and maximized the coverage area in random deployment.

Although both algorithms are good in solving a problem of coverage area, they also have their own weaknesses as well. In EVFA approach, the search for the best position is not available in finding the optimal coverage and connectivity after the relocation of sensor nodes. The algorithm stops either when the coverage requirement is met or the maximum iteration has exceeded to relocate the position of sensor nodes based on the threshold distance value.

A random walk via Levy flight in CS algorithm is more efficient in exploring the search of maximum coverage area in random deployment. However, there are lot of overlapping and coverage hole areas. These overlapping and coverage hole areas while consuming sensing capabilities did not address the issues of guaranteeing connectivity between the nodes.

The algorithm with a combination of EVFA and CS algorithm was proposed with aforementioned strength and weakness for each of the technique. The algorithm was proposed to find the optimal node placement based on the threshold distance value. The best solution of threshold distance is searched by CS algorithm using a Levy flight approach. The EVFA approach is implemented in this algorithm to relocate the sensor nodes based on the threshold distance in order to minimize the coverage and connectivity problem in random deployment.

4.5 Chapter Summary

In this chapter, the performance of EVFA and CS algorithm were evaluated based on the metric performance of coverage area and connectivity. Performance evaluation and analysis of the algorithm have been carried out using MATLAB for five replication of simulation runs using different number of sensor nodes for both EVFA and CS algorithm. In CS algorithm the replication of simulation runs were conducted based on the number of iteration. The results presented in previous sections shows that EVFA with a repulsive and attractive forces can relocate the position of sensor nodes after the initial random deployment. The algorithm shows the improvement of coverage area with a minimum overlapping and coverage hole area. The CS algorithm provides more coverage area in random deployment but there are lot of overlapping and coverage hole area. Thus, the solution provided by CS is not practical and inefficient because of the large overlapping area that will waste a number of sensor nodes.

In terms of connectivity, the EVFA approach exhibits a guaranteed connectivity and the intersection of connectivity was reduced better than CS algorithm. It has been proved that EVFA achieve a significant improvement in providing better coverage areas and connectivity compared to CS algorithm. Moreover, the analysis of elapsed time performance in EVFA and CS algorithm shows that the EVFA approach consumed less time to execute the simulation for all sensor nodes. However, the CS algorithm is chosen in this research because of the searching stability and balance randomization generated by Levy flight that gives the optimization algorithm more efficient.

CHAPTER FIVE
EXTENDED VIRTUAL FORCE AND CUCKOO SEARCH ALGORITHM FOR NODE PLACEMENT OPTIMIZATION

5.1 Introduction

This chapter discusses the analysis and results of the simulation ran for Extended Virtual Force-Based Algorithm (EVFA) and Extended Virtual Force and Cuckoo Search (EVFCS) algorithm for node placement strategy in wireless sensor networks. The simulation has been conducted using MATLAB where the simulation scenario is based on initial random deployment and relocation of sensor nodes using a group of sensor nodes for the node placement techniques. The sensor nodes were deployed in the area of 100m x 100m based on the following formula:

$$rand * 50 + (100 / 4) \tag{5.1}$$

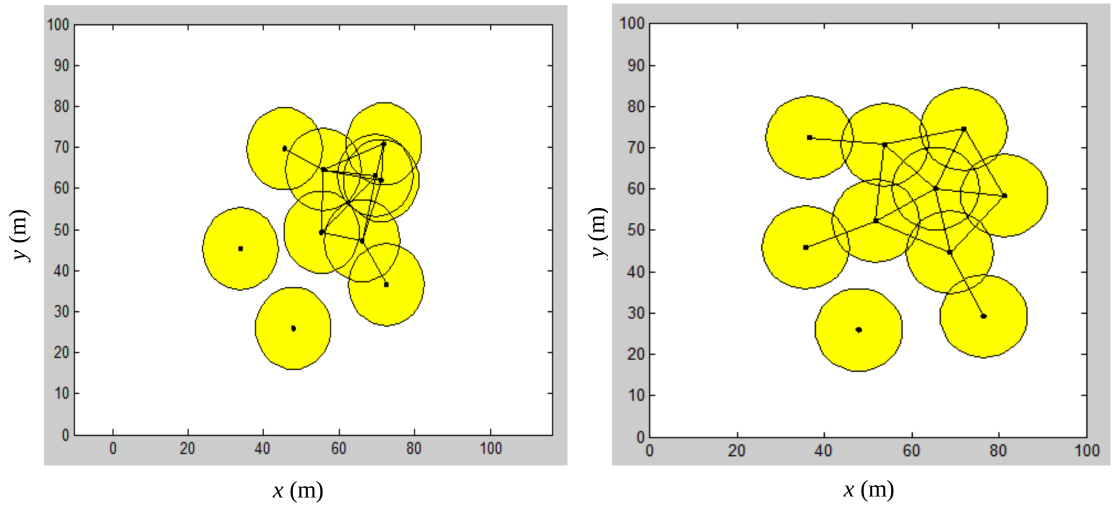
The metric performance of coverage area and connectivity were evaluated based on the ideal threshold distance in EVFA and best solution of threshold distance search by EVFCS.

5.2 Extended Virtual Force-Based Algorithm

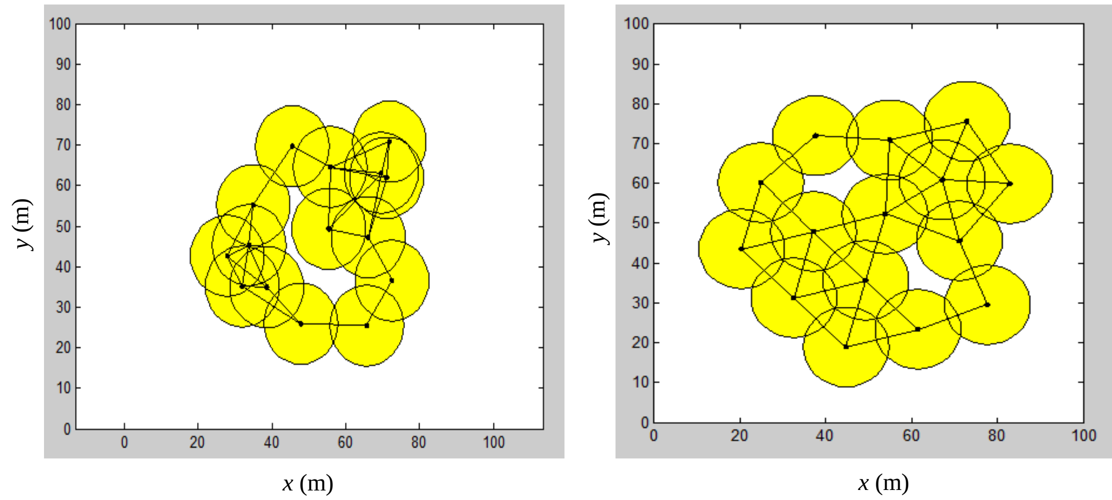
The performance of Extended Virtual Force-Based Algorithm (EVFA) was analysed in terms of its coverage area and connectivity in the initial deployment and after the relocation of sensor nodes in random deployment based on the ideal distance, $\sqrt{3}\,R_s$. In the simulation, the sensor nodes were deployed randomly using, 10, 15, 20 and 25 nodes in the area of 100m x 100m.

5.2.1 Coverage area

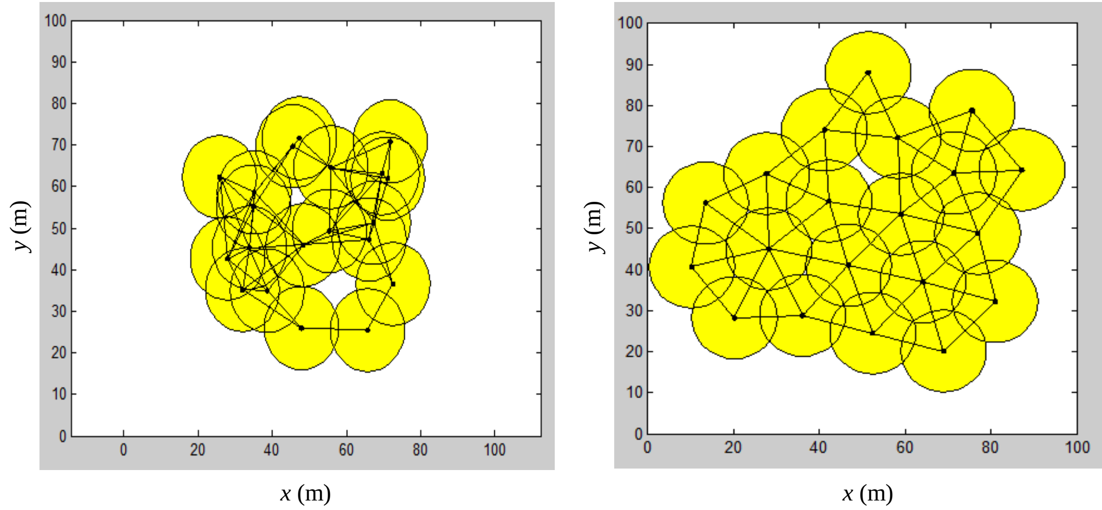
The coverage performance in EVFA approach was analysed after the relocation of sensor nodes due to the random deployment. The value of coverage area was calculated based on Equation (4.2). The sensor nodes were deployed in a static random for every simulation run to provide a fair comparison of coverage value. The parameter used in this simulation was listed in Table 4.1. Figure 5.1 illustrates the initial random deployment and after relocation of sensor nodes using EVFA approach.



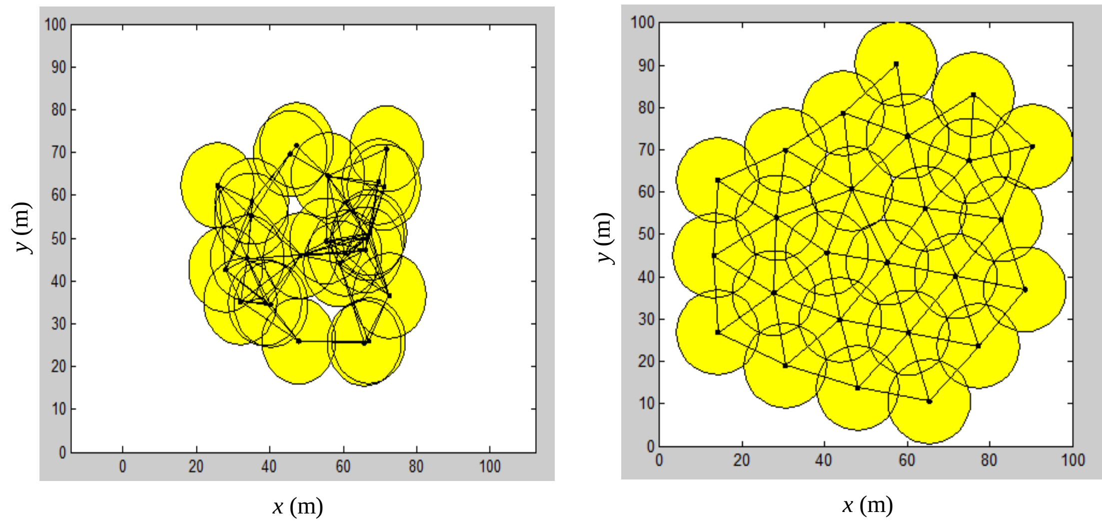
a) Initial Random Deployment and Relocation of Sensor Nodes using EVFA for 10 Nodes



b) Initial Random Deployment and Relocation of Sensor Nodes using EVFA for 15 Nodes



c) Initial Random Deployment and Relocation of Sensor Nodes using EVFA for 20 Nodes



d) Initial Random Deployment and Relocation of Sensor Nodes using EVFA for 25 Nodes

Figure 5.1: Initial Random Deployment and Sensors Relocation using EVFA

Figure 5.1 presents the initial deployment where there are overlapping of sensing area by a redundant of sensor nodes and coverage hole area in the region of interest. However, the sensor nodes were ideally deployed in EVFA approach compared to the deployment in the initial random deployment. The position of sensor nodes are relocated based on the threshold distance, $\sqrt{3}\,R_s$. The relocation of sensor nodes shown in Figure 5.1 indicated that the repulsive and attractive forces in EVFA provide an improvement of coverage area during the execution. It can be seen that the number of overlapping and coverage hole area were reduced as compared to the initial deployment. The Table 5.1 shows the results of coverage area, coverage hole and overlapping area in both initial deployment and relocation in EVFA approach. From the data in Table 5.1, it is apparent that more areas are covered by the sensor nodes due to the increment number of sensor nodes deployed. The results, as shown in Table 5.1, indicates that EVFA approach can improve the coverage area compared to the initial deployment in different number of sensor nodes used. In addition, the force pattern in EVFA influence the performance of coverage area and also give an effect to the coverage hole and overlapping area in the region of interest. The coverage hole and overlapping area are reduced after the relocation of sensor nodes. Clearly, the improvement in terms of coverage area, coverage hole and overlapping area were obtained after the relocation of sensor nodes using EVFA approach. This approach can compatibly adapted in a node placement algorithm to minimize the problem in random deployment.

Table 5.1: Results of Coverage Area of Initial Deployment and Relocation using EVFA

Performance	Number of nodes											
	10			15			20			25		
	Initial deployment (m^2)	EVFA (m^2)	% increment/ decrement	Initial deployment (m^2)	EVFA (m^2)	% increment/ decrement	Initial deployment (m^2)	EVFA (m^2)	% increment/ decrement	Initial deployment (m^2)	EVFA (m^2)	% increment/ decrement
Coverage Area	1521.4	2335.2	8.1%	1375.8	3046.1	16.7%	1426.8	3687.0	22.6%	2065.4	4330.1	22.6%
Coverage hole	8478.6	7664.8	-8.1%	8624.2	6953.9	-16.7%	8573.2	6313.0	-22.6%	7934.6	5669.9	-22.6%
Overlapping	1620.2	806.4	-8.1%	3336.6	1666.3	-16.7%	3521.4	2596.2	-9.3%	4034.8	3523.9	-5.1%

5.2.2 Connectivity

The ability to transmit and report data to the base station is known as connectivity. A network is said to be fully connected if every pair of nodes can communicate with each other either directly or via intermediate relay nodes. The simulation results in Figure 5.1 illustrated the initial random deployment and EVFA approach based on different number of sensor nodes deployed in the ROI of 100m x 100m. The connectivity between sensor nodes was represented with line. In initial random deployment, there were intersections of connectivity with redundant sensor nodes. This leads to inefficient use of sensor nodes and sensing capabilities. However, after the relocation of sensor nodes, it revealed a better connectivity when using EVFA in random deployment. The overlapping area with the intersection of connectivity was minimized after the relocation with attractive and repulsive forces. Figure 5.2 clearly shows the improvement of connectivity edge after the relocation in EVFA where the intersection of connectivity between sensor nodes were avoided. The simulation results in Figure 5.2 proved that the implementation of distance force in range of threshold distance, $\sqrt{3}\,R_s$ and communication range between sensor nodes in EVFA guarantee continuous connectivity and prevent them from the redundant sensing and connectivity intersection.

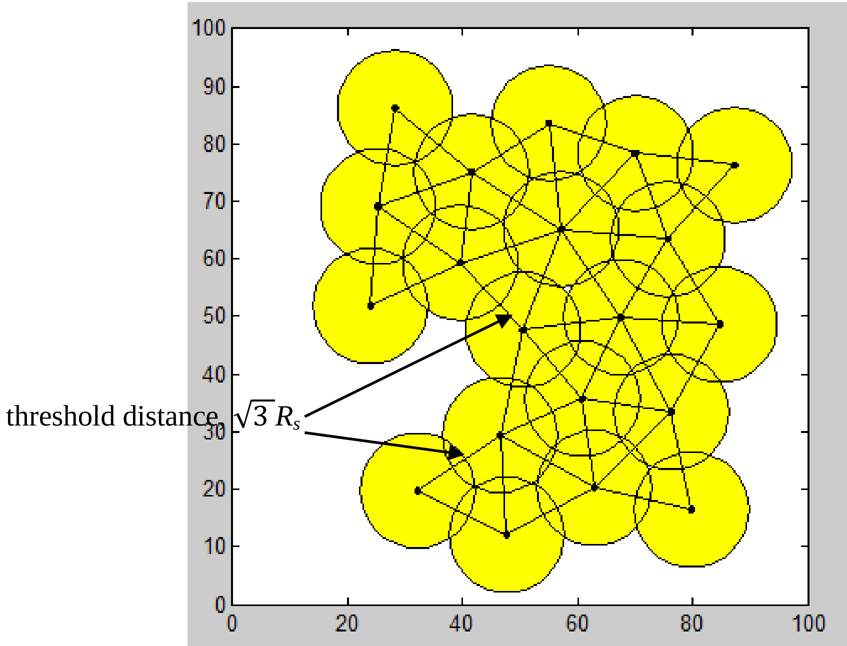


Figure 5.2: Improvement of Connectivity in EVFA Approach

5.3 Extended Virtual Force and Cuckoo Search Algorithm

The combination of EVFA and CS algorithm is constructed as an algorithm to fulfil the objectives of this thesis. The main objective of this thesis is to construct an algorithm for optimizing the node placement while minimizing the coverage and connectivity problems in random deployment. This algorithm incorporates the advantages of EVFA and CS algorithm. The EVFA uses a force-directed approach to achieve a redeployment of sensor network after an initial random deployment [12]. The EVFA approach will exert forces between the nodes either by attractive or repulsive pattern. When two nodes are close enough, the force is in repulsive pattern which intends to separate them but when two nodes are far from each other, the force becomes attractive which draws them closer. The repulsive pattern can avoid the redundant coverage or overlapping while the attractive pattern can avoid the coverage holes. The CS algorithm is used to find the best solution of threshold distance value for a maximum coverage area in a range of lower bound, L_b and upper bound, U_b. This algorithm adapted the advantages of EVFA and CS algorithm where the force pattern produced by EVFA algorithm used to relocate the position of sensor nodes for optimal node placement is based on the best solution of threshold distance value search by CS approach to minimize the problem of random deployment.

The optimal node placement pattern needs to be well planned in order to optimize the coverage and connectivity with the least number of sensor nodes. Li et al. [34] proposed an ideal deployment for self-deployment scheme using grid structure for 1-coverage. The ideal deployment has the smallest overlapping with no coverage hole exist. The ideal distance, $\sqrt{3}\,R_s$ is called the threshold distance, D_{th} between sensor nodes to limit the maximum and minimum distance from the nearest neighbour. The proposed algorithm will search the best solution of threshold distance adapted from CS algorithm. The sensor nodes then relocates using the value of threshold distance in order to find the optimal node placement with a maximum coverage area and minimum overlapping. For the implementation of the proposed algorithm in this thesis, the sensor nodes are assumed to be deployed in a random deployment scheme using a homogeneous dynamic sensor with limited movements. The parameters used in this algorithm are described in Table 5.2.

Table 5.2: Parameters used in EVFCS Algorithm

Parameter	Description
N	total number of sensor nodes
N_{est}	number of nests of different solutions
P_a	probability of discovery rate for alien eggs / solution
L_b	lower bound represents lower value of solution
U_b	upper bound represents upper value of solution
E_{dth}	egg represent a solution in N_{est}
F_{it}	fitness value

B_{nest}	best solution with $L_b < B_{nest} < U_b$
R_s	sensing range of sensor nodes
R_c	communication range of sensor nodes
D_{th}	initial value of threshold distance, $\sqrt{3}R_s$
A_{cover}	area covered by the sensor nodes
A_{ovl}	overlapping area
$D_{i,j}$	distance between sensor nodes
$F_{i,j}$	exerted on node *i* by node *j* in the network
FR	repulsive force
FA	attractive force

5.3.1 Construction of Objective Function

The objective function in this thesis is to maximize the coverage area and minimizing the overlapping and coverage hole of the sensor nodes in random deployment. In this proposed algorithm, two factors were considered when selecting an optimal solution of node placement such as coverage area and overlapping area.

a) Overlapping area

A WSN may consist of hundreds to thousands of sensor nodes that are deployed randomly. Due to the random deployment, it is common that the area covered by the sensor nodes may overlap with each other even if the nodes are uniformly distributed. The overlapping or redundant sensing of coverage will waste the sensing capability, the number of sensor and also energy. The intersection area is called an overlapping area. When overlapping occurs, two or more sensors will sense from the same target point and send replicated information to the base station. Overlapping therefore results in sensing range and energy wastages. This not only wastes the energy but also increase the number of nodes required. In this thesis, the overlapping area is calculated using a trigonometry formula for overlapping area and represented an objective function as below:

Objective function 1 : minimize the overlapping area

$$D_{i,j} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$$

$$O_{i,j} = \left(\frac{8 \times {R_s}^2 \cos^{-1} \frac{D_{i,j}}{2R_s} - D_{i,j} \times \sqrt{4 \times R_s - D_{i,j}^2}}{4} \right)$$

$$O_{i,j} = \sum_{i=1,j=1}^{N} \left(\frac{8 \times {R_s}^2 \cos^{-1} \frac{D_{i,j}}{2R_s} - D_{i,j} \times \sqrt{4 \times R_s - D_{i,j}^2}}{4} \right)$$

$$\boldsymbol{min(O_{i,j})} \quad (5.2)$$

where

$O_{i,j}$ is an overlapping area

N is a number of sensor node

$D_{i,j}$ is a distance between node i and j

R_s is a sensing range for sensor node

b) Coverage area

Coverage area is a main requirement in wireless sensor networks that affects the performance of coverage in sensing the phenomena within a region of interest. Coverage is usually interpreted as how well a sensor network will monitor a field of interest. It can be thought of as a measure of quality of service (QoS). The coverage of the monitored region can be ensured through the planning of nodes density and this affects numerous coverage performance. In this algorithm, the objective function of coverage area is to maximize the coverage area in random deployment by relocating the sensor nodes position based on the best solution of threshold distance. A sensor node's coverage area is usually modeled as a disk. Any point within an area is assumed to be sensed by the node. Each sensor node can only detect an object or phenomena within a limited range which is called the sensing range, R_s. The coverage area is calculated using the area formula as in Equation (5.3):

$$A_{total} = N * pi * R_s^2 \quad (5.3)$$

where:

N is a number of sensor node

pi represent a value of 3.142

R_s is a sensing range

Due to random deployment, the sensor nodes are assumed to have signal overlapping and coverage hole areas.

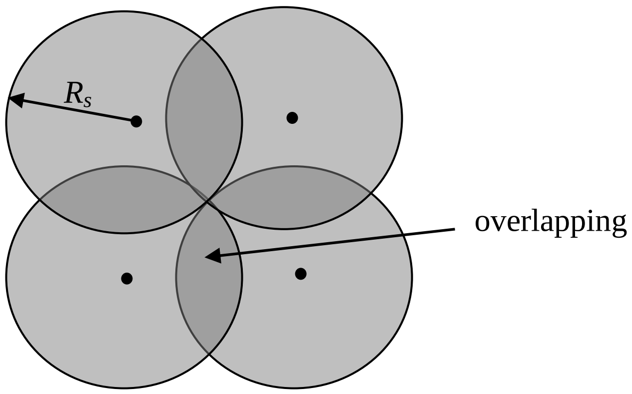


Figure 5.3: Overlapping area

As illustrated in Figure 5.3, the coverage area between the sensor nodes are included in the overlapping area. In order to calculate the coverage area, the overlapping area need to extract from the total coverage area. The formula to calculate the coverage area as in Equation (5.4).

$$A_{cover} = A_{total} - (O_{i,j}/2) \tag{5.4}$$

and represented as objective function as below:

Objective function 2 : maximize the coverage area

$$C_{i,j} = N \times \pi \times R_s^2 - (O_{i,j}/2)$$

$$C_{i,j} = \sum_{i=1,j=1}^{N} \left(N \times \pi \times R_s^2 - (O_{i,j}/2)\right)$$

$$\boldsymbol{max}(\boldsymbol{C_{i,j}}) \tag{5.5}$$

where:

N is the number of sensor node

R_s is the sensing range

$O_{i,j}$ is the overlapping area

These two objective functions are combined in one objective function, F_{obj} as below:

$$\mathbf{max}\left(\sum_{i=1,j=1}^{N}(\boldsymbol{C_{i,j}} - \boldsymbol{O_{i,j}})\right) \tag{5.6}$$

5.3.2 The Proposed Algorithm

The algorithm is proposed to find the best solution of threshold distance for optimal node placement and relocate the position of sensor nodes in order to maximize the coverage area and minimize the coverage hole and overlapping. The force strategy implemented in this algorithm which each sensor behaves as a source of force to all other sensors within its sensing range, communication range and threshold distance.

The type of force exerted by a node i on a node j depends on the distance between the two nodes. If the distance is shorter than an initial threshold distance denoted D_{th}, a repulsive force is exerted on each other. Otherwise an attractive force is exerted by each other. The attractive force will also consider the maximum distance from each sensor nodes. If the distance is more than the maximum distance, the sensor node will not be attracted and ignored or abandoned. If the distance equals to the threshold distance, no force pattern exists. The best solution of threshold distance, B_{nest} is searched by CS algorithm implemented using a Levy flight approach. The B_{nest} value is matched with a value of coverage area in order to meet the objective function of this research. Relocation of the sensor nodes is based on the N_{est} value, then the coverage area is calculated using the objective function and the best solution, B_{nest} is defined.

In the proposed algorithm, the number of nest and egg as a solution value is identified. The ranges of solutions, E_{dth} are generated within the L_b and U_b value which is set to 3.0 and 3.5 meters. The lower and upper bound values refer to the square root value in the threshold distance (sqrt (L_b, U_b) x R_s). Then, N numbers of sensor nodes are randomly deployed in a range area of xm x ym. After that, the algorithm calculated the distance between sensor nodes using the Euclidean distance formula, $D_{i,j} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$ and relocate the position of sensor nodes based on the initial threshold distance $\sqrt{3}\,R_s$ using EVFA approach. The exerted force on sensor nodes is based on these conditions:

Condition 1:

If the distance between sensor nodes are more than initial threshold distance, $\sqrt{3}\,R_s$ then attractive force will be used to attract the sensor nodes position. The expression of attractive force is shown as below:

$$if\ D_{i,j} > D_{th}$$

$$FA\sim_{ij} = \left(D_{i,j} - D_{th}\right),\ \alpha_{i,j}$$

Condition 2:

If the distance between sensor nodes are less than initial threshold distance, $\sqrt{3}\,R_s$ then repulsive force will be used to repulse the position of sensor nodes. The expression of repulsive force is shown as below:

$$if\ D_{i,j} < D_{th}$$

$$FR\sim_{i,j} = \left(\frac{1}{D_{i,j}}, \alpha_{i,j} + \pi\right)$$

Condition 3:

If the distance between sensor nodes are equal to the initial threshold distance, $\sqrt{3}\,R_s$, then no force pattern exert will use as shown in the expression below:

$$if\ D_{i,j} = D_{th}$$

$$F_{i,j} = 0$$

The exerted on node i by node j in the network (denoted by F_{ij}) as the equation below:

$$\overrightarrow{F_{i,j}} = \begin{cases} F_A\left(D_{i,j} - D_{th}\right), \alpha_{i,j} & if D_{i,j} > D_{th} \\ 0 & if D_{i,j} = D_{th} \\ F_R D^{-1}{}_{i,j}, \alpha_{i,j} + \pi & if D_{i,j} < D_{th} \end{cases} \tag{5.7}$$

Next, the algorithm will calculate the coverage area and overlapping area. The initial coverage area is set as fitness value, F_{it}.The algorithm will find the fitness value for each egg, E_{dth} in N_{est} from the objective function, F_{obj}. In F_{obj}, the sensor nodes are randomly deployed and relocated using the E_{dth} value of solutions using EVFA approach. Then the coverage area and overlapping area are calculated. The new solutions are evaluated to find the best solution by comparing the fitness value, F_{it} with the maximum value of coverage area from the combination of coverage area and the E_{dth} value. The CS algorithm approach is used to randomly generate the new solution using Levy flight within the boundary of L_b and U_b values. A fraction of worst nest, P_a will be removed and replaced by some nests by constructing new solutions while keeping the best solution, B_{nest}. In this algorithm, a probability, P_a = 0.25 from a number of solution is removed from the nest. The combination of fitness and the potential solution are sorted in ascending order. The relocation of sensor nodes using a maximum threshold distance is assumed to have a coverage hole, so in this algorithm the highest value in nest is set as a worst nest. The new fitness value is evaluated from the objective function F_{obj} and the best nest value is ranked in order to find the best solution. The algorithm for optimal node placement is shown as below:

Algorithm 3: Extended VFCS Algorithm for Optimal Node Placement in WSN

Step 1. **Initialization:**

Parameter : N, N_{est}, P_a, R_s, R_c, L_b, U_b, $D_{i,j}$, D_{th}

Generate initial set of eggs in range L_b and U_b set to [3.0, 3.5]

Generate the deployment of sensor nodes randomly

Step 2. **Calculation:**

Distance, D using Euclidean distance

$$D_{i,j} = \sqrt{(x_1 - y_1)^2 + (x_2 - y_2)^2}$$

Relocate sensor nodes based on optimal D_{th}, $\sqrt{3}\,R_s$ using EVFA

Calculate the overlapping area, $O_{i,j}$

Calculate the coverage area, A_{cover}

Set initial coverage area = fitness, F_{it}

Step 3. **Find the fitness value:**

Generate the deployment of sensor nodes randomly

For 1 to total number of N_{est}

Call the objective function

Relocate sensor nodes based on potential solutions using EVFA based on the following condition:

Condition 1: (Attractive force)

$if\ D_{i,j} > E_{dth}$

$$FA{\sim}_{i,j} = \left(D_{i,j} - E_{th}\right),\ \alpha_{i,j}$$

end if

Condition 2: (Repulsive force)

$if\ D_{i,j} < E_{dth}$

$$FR\sim_{i,j} = \left(\frac{1}{D_{i,j}}, \alpha_{i,j} + \pi\right)$$

end if

Condition 3:

$if\ D_{i,j} = E_{dth}$

$F_{i,j} = 0$

end if

Calculate the overlapping area, $O_{i,j}$

Calculate the coverage area, A_{cover}

End for

Find B_{nest}

Step 4. **Iteration**

For 1 to number of iteration

Generate potential solutions randomly using Levy Flight within L_b and U_b

For1 to total number of N_{est} size

Implement random walk to generate potential of solutions

Call simplebound function

Set the potential solution as a temporary nest

ns_tmp = s;

Apply the lower bound

I= ns_tmp < Lb;

ns_tmp(I) = Lb(I);

Apply the upper bounds

J= ns_tmp > Ub;

ns_tmp(J) = Ub(J);

Update this new move

s= ns_tmp;

End for

Calculate the current fitness, F_{obj}

Remove a fraction of worst nest, P_a and keep best solution, B_{nest}

Sort the fitness and nest value

Sort_fitness_nest = sortrows (fitness_nest)

Remove worst nest (P_a= 0.25 from the number of N_{est})

Remaining a good nest and generate new potential solution

Calculate the new fitness, F_{obj}

Rank the best nest, B_{nest}.

End for

Repeat Step 4 until maximum iteration

Step 5: **Result**

B_{nest} = best solution of threshold distance

Relocate sensor nodes base on B_{nest} value

When the algorithm terminates, B_{nest} will be the best solution of the threshold distance value. The relocation of sensor nodes is based on B_{nest} and F_{it} will be the best coverage area with N number of sensor nodes, R_s and R_c values. The process of the algorithm is shown in Figure 5.4.

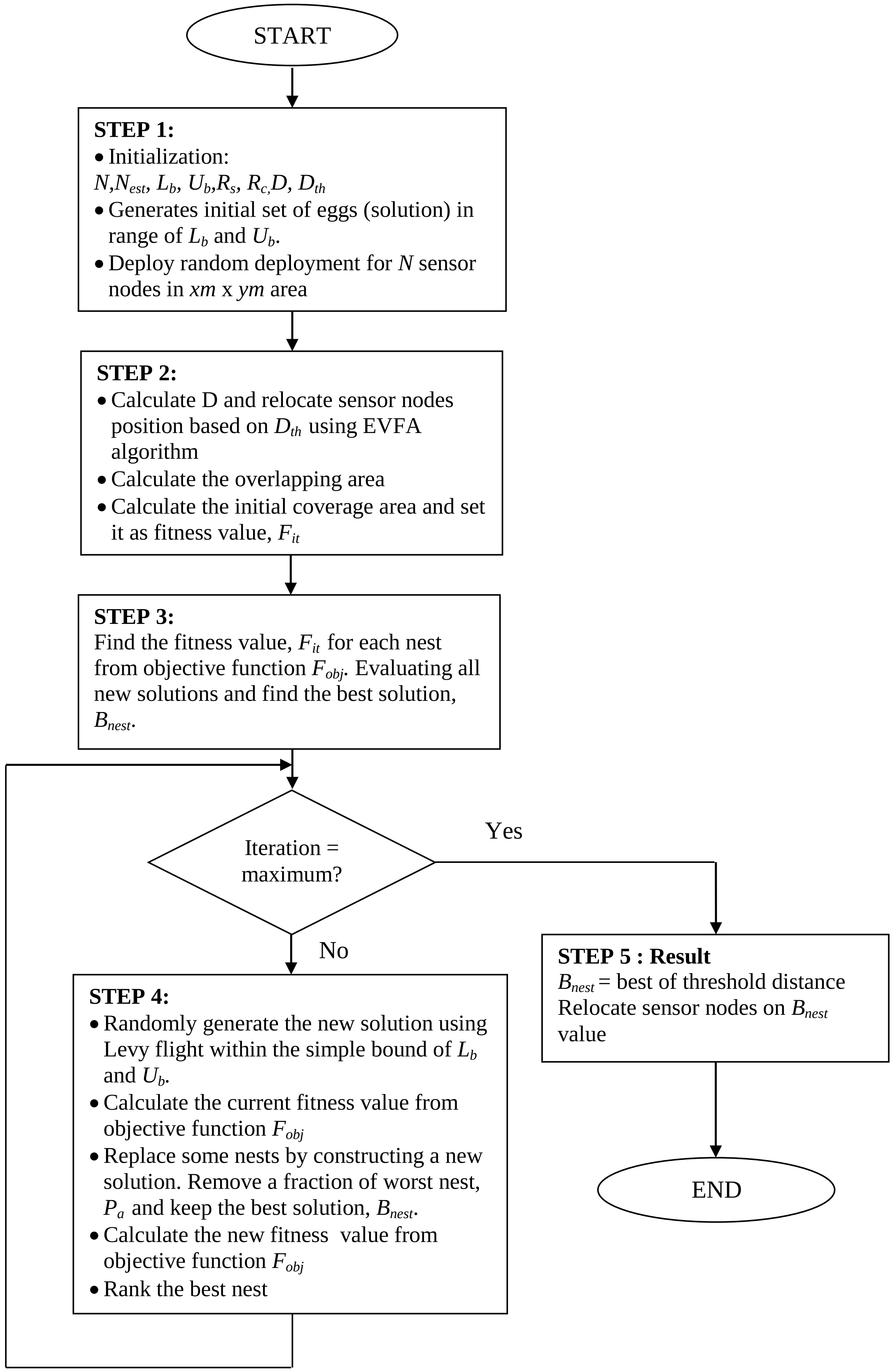


Figure 5.4: Flowchart of Extended Virtual Force and Cuckoo Search Algorithm

The performance of EVFCS algorithm is evaluated in terms of coverage area and connectivity after relocation of sensor nodes in random deployment. The relocation of sensor nodes is based on the threshold distance, D_{th}, between sensor node. The simulation was conducted in a group of sensor nodes for a different number of iterations. In EVFCS algorithm the range of potential solution was set in a range of lower bound, L_b, and upper bound, U_b. The value of lower bound was set to 3.0 and upper bound is set to 3.5 which is refer to the minimum and maximum of proposed threshold distance value. In EVFCS algorithm, the metric performance of coverage and connectivity were evaluated based on the best solution of threshold distance value, D_{th}. In order to provide a fair result, the deployment of sensor nodes was simulated randomly inconstant random deployment.

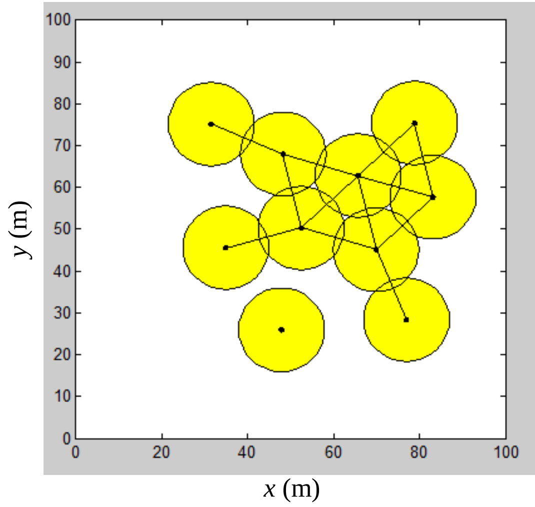
5.3.3 Coverage Area

The objective function in the EVFCS was to measure the performance of the coverage area in the region of interest. The main aim was to maximize the coverage area thus reducing the overlapping and coverage hole area. In EVFCS, the coverage performance was evaluated based on the best solution of minimum and maximum threshold distance values for the overall iteration where a sensing range was set to 10 meter. From the simulation, the minimum threshold distance value search by this algorithm was 18.215 meter and the maximum value was 18.707 meter. The performance of coverage area based on minimum and maximum threshold value is shown in Table 5.3 and Table 5.4 respectively.

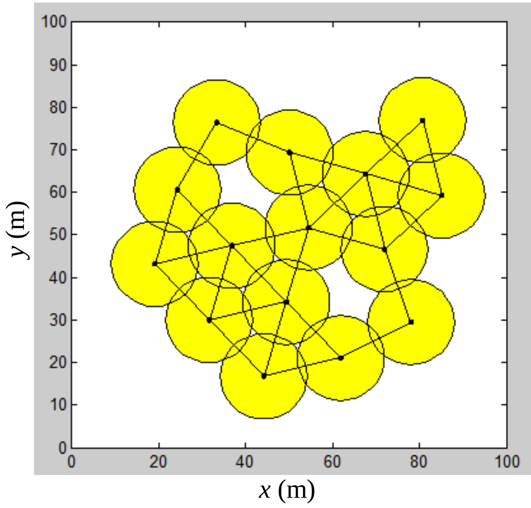
Table 5.3: Coverage Performance in EVFCS with Threshold Distance = 18.215 meter

Number of nodes	Coverage Area (m^2)	Coverage hole (m^2)	Overlapping (m^2)
10	2571.2	7428.8	570.4
15	3476.6	6523.4	1235.8
20	4524.9	5475.1	1758.3
25	5289.4	4710.6	2564.6

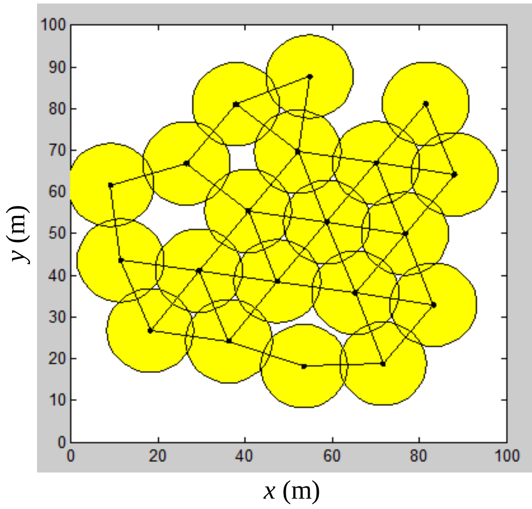
From the data in Table 5.3 and Table 5.4, the best coverage performance of 10 nodes is between 2571.2m^2 and 2749.3m^2. In the EVFA approach with threshold value of $\sqrt{3}\,R_s$ or 17.32 meter, the coverage area for 10 nodes was 2335.2m^2. The simulation results show the coverage performance of 10 nodes in EVFCS was efficient compared to the EVFA approach. There are positive improvements in terms of reduction in coverage hole and overlapping area in EVFCS where the coverage hole and overlapping area is lower than EVFA approach. Figure 5.5 illustrates the relocation and the coverage performance of sensor nodes using the minimum threshold distance value search by EVFCS for group of sensor nodes in the simulation runs.



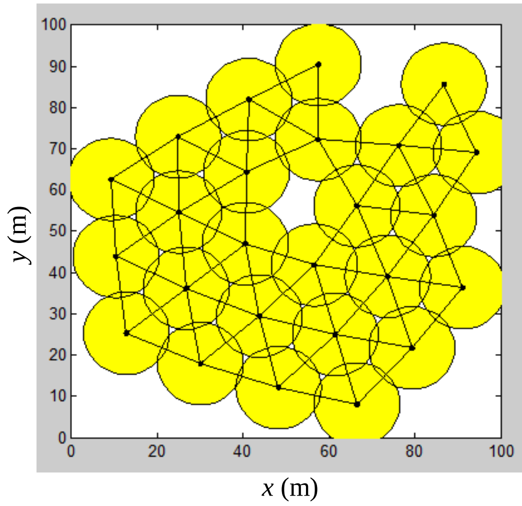
a) Node = 10



b) Node = 15



c) Node = 20



d) Node = 25

Figure 5.5: Relocation of Sensor Node and Coverage Performance with Threshold Distance = 18.215 meter

The performance of coverage area based on the maximum threshold distance value of 18.707 meter search by EVFCS algorithm is shown in Table 5.3. The data from the table shows the coverage areas are increased slightly 10% for all group of sensor nodes. The coverage hole and overlapping area were minimized compared to the relocation of sensor nodes using a minimum threshold distance, 18.215 meter. The overlapping area for 10 nodes relocated using 18.707 meter of threshold distance was reduced as compared to the deployment in minimum threshold distance value.

Table 5.4: Coverage Performance in EVFCS with Threshold Distance = 18.707meter

Number of nodes	Coverage Area (m^2)	Coverage hole (m^2)	Overlapping (m^2)
10	2749.3	7250.7	392.2
15	3810.2	6189.8	902.2
20	4832.2	5167.8	1451.0
25	5863.2	4136.8	1990.8

The comparison of coverage performance in minimum and maximum threshold distance value in EVFCS is shown in Figure 5.6. Thus the coverage area can be maximized while minimizing the coverage hole. The performance of coverage area, coverage hole and overlapping area for the maximum threshold distance value is illustrated in Figure 5.7.

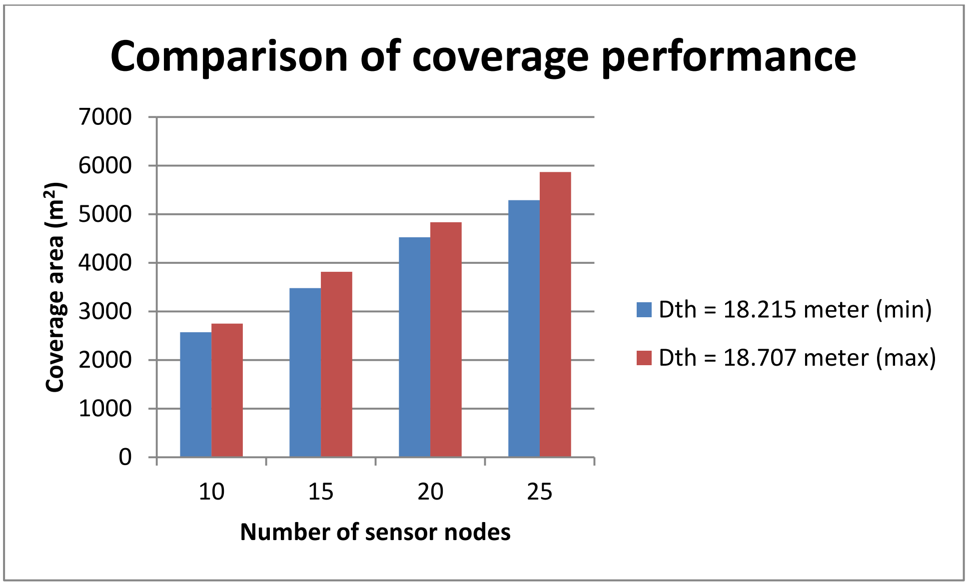


Figure 5.6: Comparison of Coverage Performance in Minimum and Maximum Threshold Distance in EVFCS

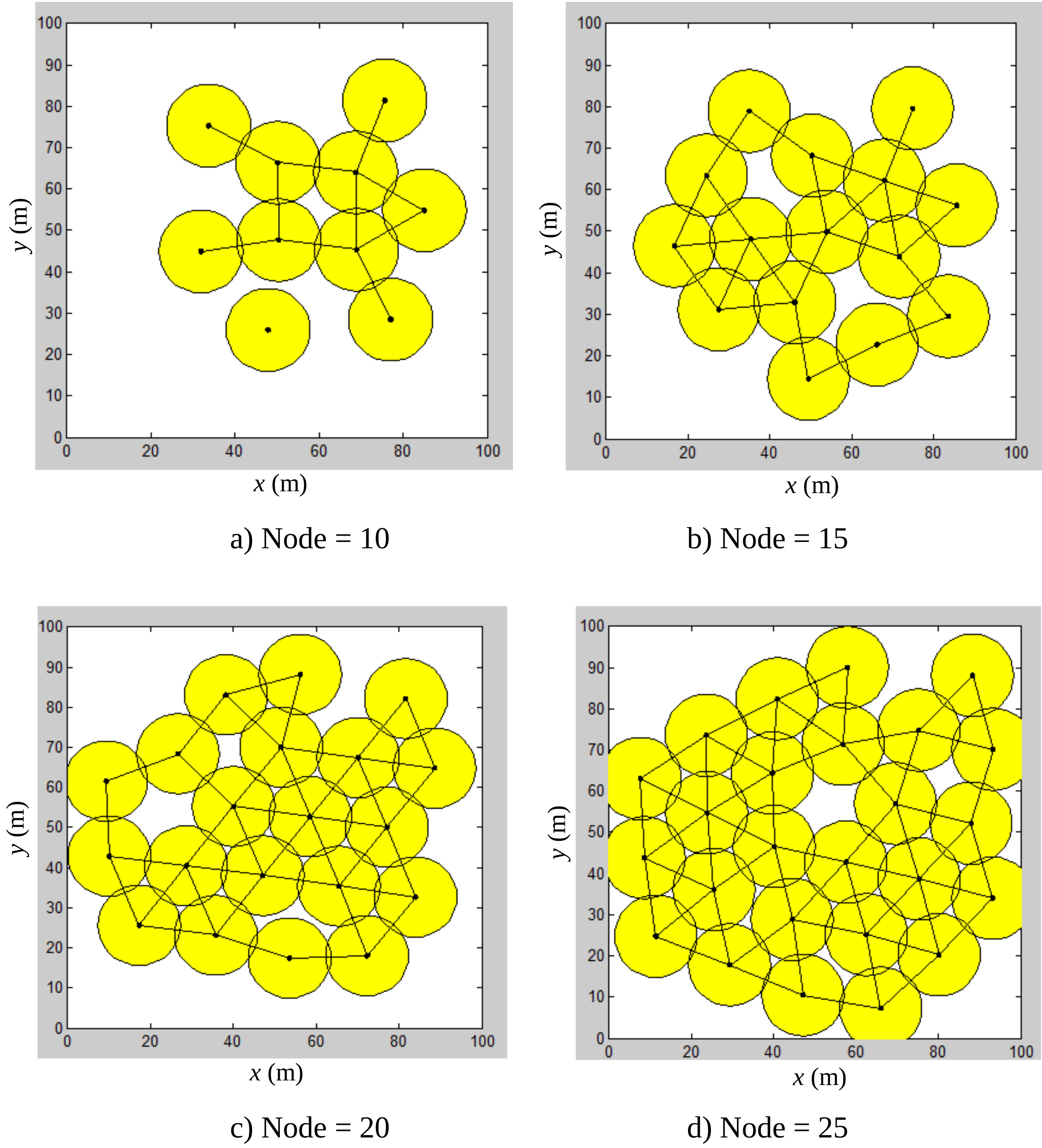
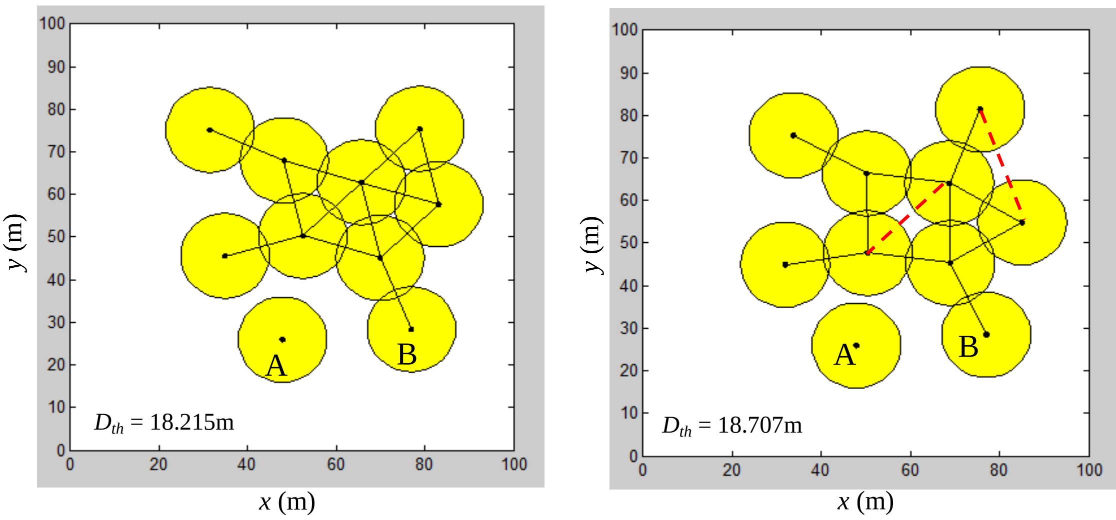


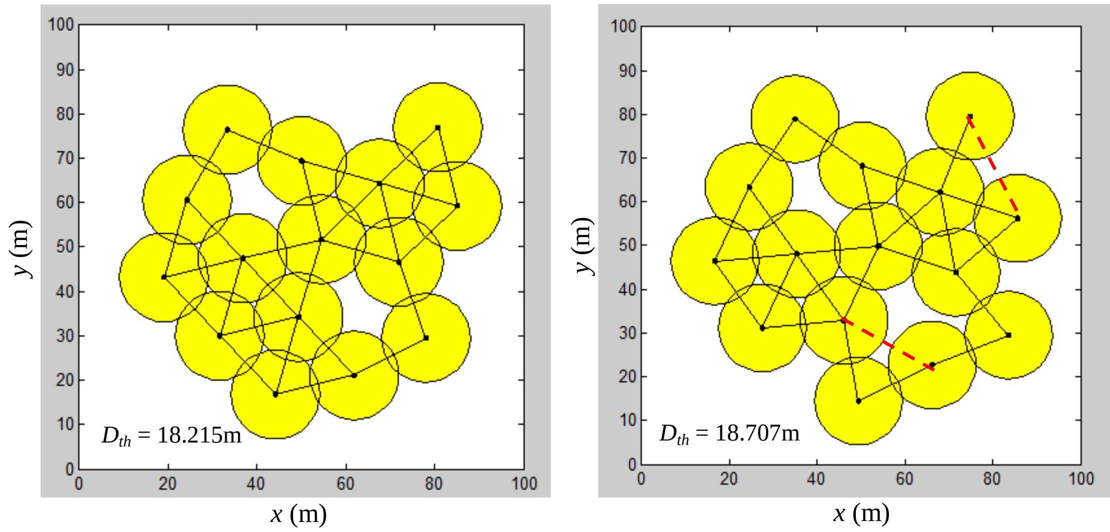
Figure 5.7: Relocation of Sensor Node and Coverage Performance with Threshold Distance = 18.707 meter

5.3.4 Connectivity

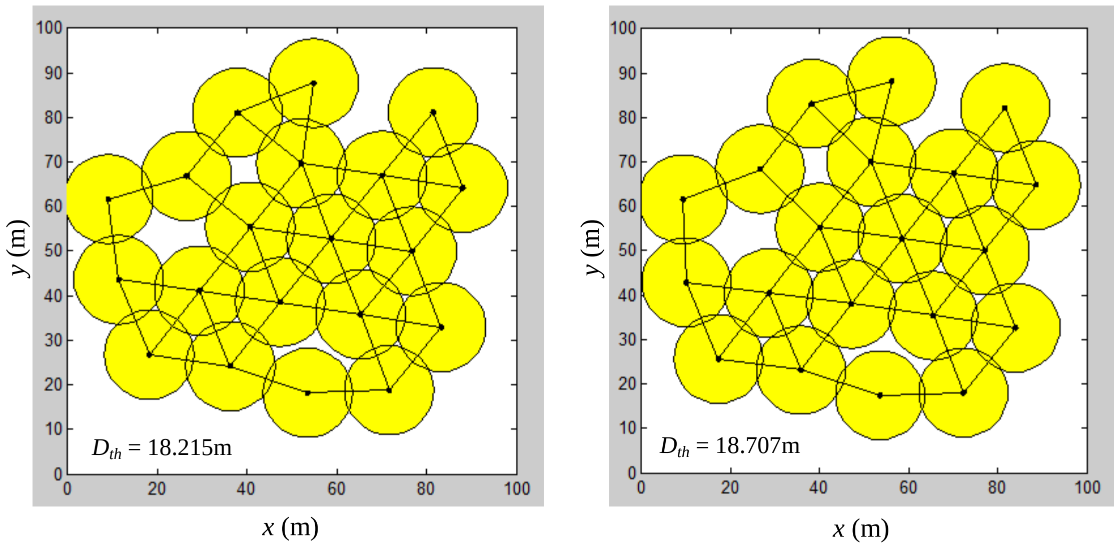
The performance of the EVFCS in terms of the connectivity was evaluated based on both minimum and maximum threshold distance value. Figure 5.8 shows the comparison of connectivity between sensor nodes after the relocation of sensor nodes using the minimum and maximum threshold distances. The line represented the connectivity between sensor nodes. As illustrated in Figure 5.8, the connectivity between the sensor nodes is guaranteed using both of threshold distance value. However, there were some numbers of sensor nodes that were not connected with the implementation of maximum threshold distance value in the relocation of sensor nodes. The dotted red line in Figure 5.8 shows the sensor nodes that are not connected to each other. The relocation of sensor nodes based on D_{th} = 18.215 meter, shows all nodes are connected compared to the relocation with D_{th} = 18.707 meter except for the nodes A and B. Figure 5.8(a) shows that the nodes A and B are not connected because the distance between nodes are more than the threshold distance value for both minimum and maximum D_{th} values. Due to the multi-hop communication of WSNs, a network is said to be fully connected if every pair of nodes can communicate with each other, either directly or via intermediate relay nodes.



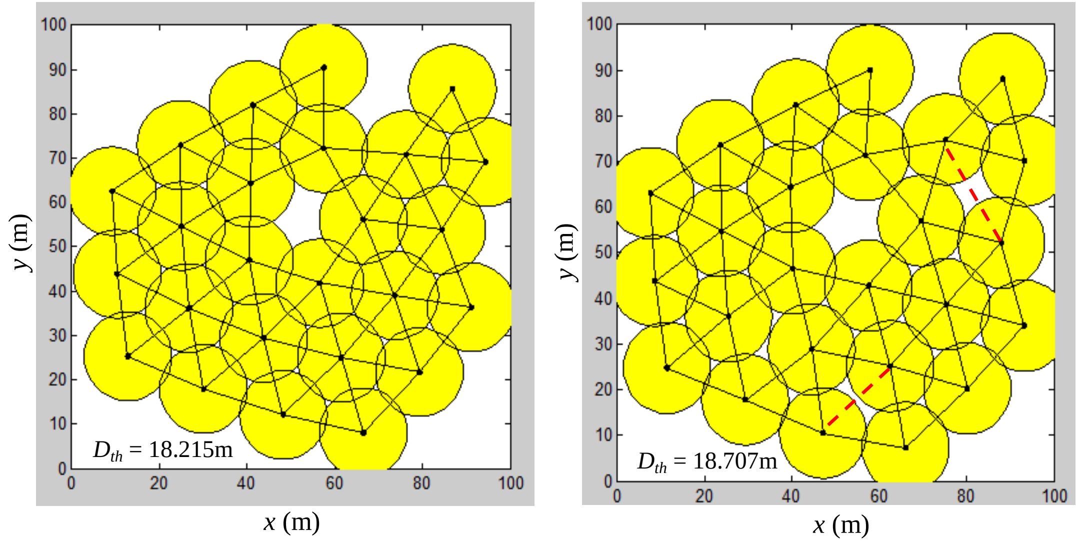
a) Relocation of 10 Nodes Based on D_{th} = 18.215 meter and D_{th} = 18.707 meter



b) Relocation of 15 Nodes Based on D_{th} = 18.215 meter and D_{th} = 18.707 meter



c) Relocation of 20 Nodes Based on D_{th} = 18.215 meter and D_{th} = 18.707 meter



d) Relocation of 25 Nodes Based on D_{th} = 18.215 meter and D_{th} = 18.707 meter

Figure 5.8: Connectivity Performance in EVFCS using Minimum and Maximum Threshold Distance Values.

5.4 Coverage Performance Comparison for EVFA and EVFCS

The performance of EVFA and EVFCS algorithm were evaluated in terms of coverage area and connectivity in random deployment. In order to have a fair result for both EVFA and EVFCS, the simulation was conducted in constant random deployment. Figure 5.9 shows the coverage performance of EVFA and EVFCS algorithm. The graph shows the improvement of the coverage area in EVFCS algorithm compared to EVFA. In EVFCS, the deployment of 25 nodes can cover up to 6000m^2 of coverage area after the relocation with a maximum threshold value of 18.707m. In contrast, the deployment of 25 nodes in EVFA approach only covers up to 4000m^2 of the coverage area after the relocation of sensor nodes.

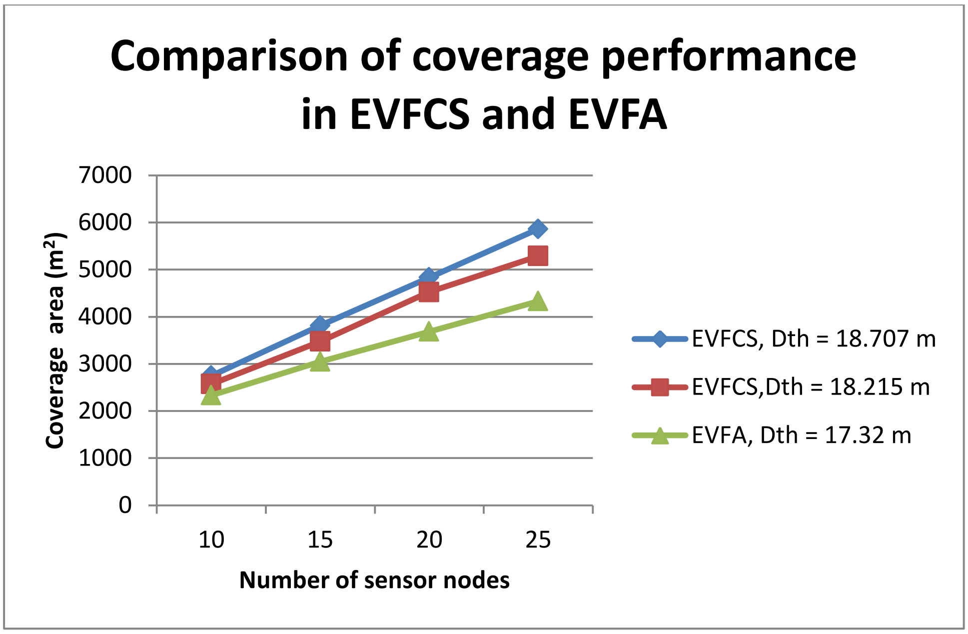


Figure 5.9: Comparison of Coverage Performance in EVFCS and EVFA Approach

In the simulation, the sensor nodes for EVFA and EVFCS algorithm were randomly deployed in the area of 100m x 100m. The percentage of effective coverage area after the execution of EVFA and EVFCS was shown in Table 5.5. The effective performance of coverage area was slightly improved between 6% to 10% due to the increment of sensor nodes deployed in the region of interest. From the deployment of 10 to 25 nodes, it shows that the coverage performance of EVFCS obtained was higher than EVFA. This is associated with the impact of the minimum and maximum threshold distance value search by EVFCS algorithm. Obviously the EVFCS algorithm with a 18.707m of threshold distance value provides the biggest effective coverage area. It can be seen that the proposed approach of EVFCS algorithm outperforms the EVFA algorithm between 5% and 16% in the terms of coverage performance which is the main objective of the implementation of these algorithms.

Table 5.5: The Effective Coverage Area of EVFA and EVFCS Algorithm

Number of nodes	EVFCS		EVFA
	D_{th}= 18.707m	D_{th} =18.215m	D_{th}= 17.32m
10	28%	26%	23%
15	38%	35%	31%
20	48%	45%	37%
25	59%	53%	43%

5.5 Chapter Summary

In this chapter, the performance of Extended Virtual Force Algorithm (EVFA) and Extended Virtual Force and Cuckoo Search (EVFCS) algorithm was evaluated based on their performance to improve the coverage area and connectivity. A performance evaluation and analysis of the algorithm has been carried out based on the threshold distance value with a different number of sensor nodes for both EVFA and EVFCS algorithms. In the simulation, the threshold value for EVFA was set to 17.32m or $\sqrt{3}\,R_s$ which was assumed as an ideal threshold value in EVFA approach. The EVFCS provides a local searching for the best solution using minimum and maximum threshold distance where the values are 18.215m and 18.707m. The results presented in previous sections proved that EVFCS has better performance in terms of coverage area with less overlapping and coverage hole area compared to EVFA approach.

In terms of connectivity, the EVFA and EVFCS algorithms exhibit a guaranteed connectivity and the intersection of connectivity can be avoided. However, the EVFCS with a minimum threshold distance value indicated a fully connected network compared to the relocation of sensor nodes with a maximum threshold distance value. It has been proved that the proposed EVFCS with a minimum threshold distance value of 18.215m achieved a significant improvement in coverage area and at the same time guaranteed connectivity. The relocation of sensor nodes with 18.215m of threshold distance value outperform the EVFA approach and make it as an optimal threshold distance value for optimal node placement in random deployment in WSN.

CHAPTER SIX
CONCLUSION

In wireless sensor network, sensor nodes can be deployed either in a deterministic or random deployment depending on the various WSN applications. However, random deployment strategy is the best option of deployment for the WSN application with a large area that is inaccessible due to difficult terrain such as in disaster, forest and a dangerous area. Nevertheless, the major challenge in random deployment that is related to performance of WSN application operation and QoS. Due to random deployment, the sensor nodes are scattered randomly where some area will not be covered and the connectivity between sensor nodes are not guaranteed. The problem of coverage hole, overlapping and connectivity failure is a major problem in random deployment. Therefore it is important to design an optimal node placement in order to improve the coverage and connectivity problems in random deployment. Throughout this thesis, the focus has been on the construction of an optimal node placement with the objective to maximizing the coverage area and minimizing the coverage hole and overlapping area while guaranteeing connectivity. In this chapter, the completed work is summarised and some suggestions are presented for future research.

6.1 Summary of Completed Research

The basic principle of wireless sensor network environment is reviewed in Chapter Two, which includes the random deployment scenarios and problems that give an impact to most applications in sensor networks. The problems of random deployment related to coverage and connectivity were identified. Due to random deployment, the sensor nodes were randomly deployed in the region of interest. The coverage hole, overlapping and connectivity failure were the main problems in random deployment strategy that affect the performance of operation and QoS in WSN application. The node placement relocation algorithm was proposed to solve and improve the coverage and connectivity problem of the sensor nodes. The measure of sensing range and communication range are important since the WSN goal is to sense and monitor the phenomena within the region of interest and transmit the information to the base station. This thesis used a disk sensing model to measure the sensing and communication range for coverage and connectivity requirement in the proposed algorithm. An Extended Virtual Force-Based Algorithm (EVFA) combining with a bio-inspired optimization technique was used to construct the algorithm in order to find the best node placement and address the problems in random deployment.

The methodology where adopted in this thesis was presented in Chapter Three. The hybrid algorithm for optimal node placement with a combination of Extended Virtual Force-Based Algorithm (EVFA) and Cuckoo Search (CS) algorithm was conducted to find the optimal solution of node placement in order to maximize the coverage area, minimize the coverage hole and overlapping while guaranteeing the connectivity. In the Extended VFCS (EVFCS), CS algorithm is adopted to find the best solution for threshold distance value and the process of relocation of sensor nodes was conducted by EVFA approach. The experiment and evaluation was conducted using MATLAB to show the coverage and connectivity performance from the proposed algorithm. In Chapter Four, a full performance of EVFA and CS algorithm was evaluated based on the metric performance of coverage area and connectivity. A performance evaluation and analysis of the algorithm has been carried out with five replications of simulation runs using a different number of sensor nodes for both EVFA and CS algorithms. The performance comparison between the EVFA and CS algorithms show that EVFA is more efficient to improve the coverage area with less overlapping and coverage hole area. The CS algorithm provides better coverage area in random deployment but there were a lot of overlapping and coverage hole areas. Thus, the solution provided by CS is not practical and inefficient to be implemented to solve the coverage problem in random deployment. The EVFA is better than CS algorithm in terms of connectivity where the intersection of connectivity can be avoided and connectivity is guaranteed. The analysis of elapsed time performance in EVFA and CS algorithms shows that the EVFA approach consumed lesser time in the simulation run for every number of sensor nodes. It can be concluded that EVFA achieve a significant improvement in coverage area and connectivity compared to CS algorithm in random deployment.

In Chapter Five, the performance of EVFA and EVFCS algorithm was evaluated based on the metric performance of coverage area and connectivity. The optimal threshold distance value for EVFA was set as $\sqrt{3}\,R_s$. The EVFCS finds the best solution for threshold distance value within the lower bound and upper bound values. The EVFCS provides a local searching for the best solution of minimum and maximum threshold distance where the values are 18.215m and 18.707m. A performance evaluation and analysis of the algorithm was carried out based on the threshold distance values with different number of sensor nodes for both EVFA and EVFCS algorithms. From the simulation results, the EVFCS improved the coverage area with lesser overlapping and coverage hole area compared to the EVFA approach. Both EVFA and EVFCS perform better in terms of connectivity where the connectivity is guaranteed after the relocation of sensor nodes. However, the EVFCS with a minimum threshold distance value shows a fully connected network compared to the relocation of sensor nodes with a maximum threshold distance value. The minimum threshold distance value of 18.215m achieved a significant improvement in coverage area and connectivity. The relocation of sensor nodes with 18.215m of threshold distance value outperforms the optimal threshold distance value in EVFA approach. Thus, by using the 18.215m of threshold distance value, it has been proved to be practical and efficient as the optimal threshold distance value for optimal node placement in random deployment in WSN.

6.2 Contribution

This thesis is focus on development of algorithm for optimal node placement in WSN random deployment. The contributions are summarized in the following subsection.

- The goal of this study was to contribute to the body of knowledge in WSN research by developing an EVFCS algorithm for optimal node placement. To accomplish this goal, the research has been conducted using a simulation scenario for random deployment of sensor nodes. The EVFCS is compared with the EVFA approach in terms of coverage and connectivity to validate the proposed EVFCS algorithm. The results show that the implementation of the EVFCS addressed the problems of initial random deployment such as overlapping area, coverage hole and connectivity failure.
- This thesis presented the EVFCS algorithm as a new approach of sensor node deployment. The EVFCS is developed to tackle the problems related to initial random deployment of sensor nodes. The capabilities of EVFA approach and CS algorithm are adapted in EVFCS in order to find the optimal node

placement with a maximum coverage area and minimum overlapping and coverage hole areas. The CS algorithm adapted in EVFCS is used to search the best solution of threshold distance value, D_{th}. Then the best solution of D_{th} is used to relocate the sensor nodes using the attractive and repulsive forces.

- WSN can be implemented to support many applications including security, military, smart agriculture, smart home, habitat monitoring and disaster monitoring. Random deployment of WSNs is needed in many applications due to the large scale of the network required such as battlefield surveillance and environmental monitoring. Some problems however, might arise due to random deployment such as overlapping area, coverage hole and connectivity failure. This research addresses these constraints by proposing and solving an optimization problem which maximizes the coverage area and minimizes the problems of random deployment. The development of EVFCS algorithm in this research can be implemented in various sensor applications in Malaysia such as geographical information system, border surveillance, flood monitoring and traffic monitoring.

6.3 Future Research

Although this thesis has proposed the EVFCS algorithm for optimal node placement in wireless sensor networks by using various performance metrics, there is still much work to be done in this area. Based on this thesis, the following research can be carried out:

- Heterogeneous sensor node

  In real life, WSN environment requires collaboration among multiple types of heterogeneous sensor nodes with different specifications. Heterogeneous sensor nodes consist of different types of sensor nodes with different sensing capabilities, battery capacities and functionalities. Placing a few heterogeneous nodes in a wireless sensor network field is an effective way to increase network lifetime and reliability. Possible future work could be to explore ways to optimize placement of heterogeneous nodes with unequal sensing and communication range in random deployment.

- Energy and network lifetime

Energy efficiency and extended network lifetime are plenary issues in WSN. The proposed algorithm was evaluated based on the metric of coverage and connectivity. There is a lot of work that depends on the locomotion capability of the sensors to relocate the sensor nodes after the initial deployment. However for mobile sensors mobility is the most power consuming task. When placing a node, energy is consumed when a node is relocated. Therefore, the optimal distance to move a node needs to be determined to strike a balance between energy consumption and coverage. Careful placement of sensor nodes will ensure that nodes perform in a more energy efficient manner thus extending the network lifetime and improving its connectivity.

- Node clustering and scheduling

Due to limited battery capacity, sensor nodes have to manage their energy consumption. They should avoid unnecessary energy consumption during their operation to increase the network lifetime. Scheduling and selection of cluster head is the common way of prolonging network lifetime in directional sensor networks. When each point in an ROI is covered by at least *k* sensor nodes, some of these sensor nodes can be set into sleep mode so that the energy can be conserve and prolong the network lifetime. Cluster heads also serve as fusion points for aggregation of data, so that the amount of data transmitted to the base station can be reduced.

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