Optimal Sensor Deployment in Internet of Things based Wireless Sensor Network for Irrigation Management System

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Abstract— In recent years, several applications are found to be exploiting under Wireless Sensor Networks (WSNs), and more particularly civil and military applications. However, Target Coverage (TCOV) and Network Connectivity (NCON) are found to be the most crucial issues that have to be resolved to attain effective robust data communication and environmental sensing in WSN. This paper has made an attempt to propose a new effective sensor deployment model in the application of the irrigation management system in agriculture sector. The data logger (data collector) IoT devices are typically placed over the field, which does the communication one another. The main point of this design is the IoT device TCOV and NCON, and the real-time issue related to this design is the device mobility that consumes more power thereby minimizes the lifetime of network. The proposed model intends to solve the comprised NCON and TCOV with the aid of Euclidean Spanning Tree Model (ECST). Further, this paper introduces a new Fitness Interrelated Whale Optimization Algorithm (FI-WOA) that insisted in the minimum movement of mobile sensors over the network. This novel characteristic of sensor deployment model would create the effectual impacts in the irrigation management system. Further, the adopted ECST-WOA model is compared with conventional models and the results attained from the execution demonstrate the enhanced performance of the implemented technique.

Keywords— Wireless Sensor Network; Coverage; Connectivity; Mobile sensor; Whale Optimization.

Nomenclature

Abbreviation	Description
WSNs	Wireless Sensor Networks
TCOV	Target Coverage
NCON	Network Connectivity
MSD	Mobile Sensor Deployment
ECST	Euclidean Spanning Tree Model
WOA	Whale Optimization Algorithm
BS	Base Station
CI	Contextual Information
BCBS	Blind-Zone Centroid-Based Scheme
PLs	Preferred Locations
CG	Carrier Glider
CMMSDP	Coverage Maximizing Mobile Sensor Deployment Problem
CRMC	Concurrent Rotation And Motion Control
SRMC	Staged Rotation And Motion Control
ESA	Efficient Self-Deployment Algorithm
SPCCA	Shortest Path Connectivity And Coverage Algorithm
GA	Genetic Algorithm
MI	Magnetic Induction
BCS	Baja California Sur
GUI	Graphical User Interface
POMDP	Partially Observed Markov Decision Process
WSUs	Wireless Sensor Units
WIU	Wireless Information Unit
HTTP	Hypertext Transfer Protocol
MDST	Minimum Distance Spanning Tree
NPV	Net Present Value
SSW	Smart Sensor Web
IAs	Irrigation Actions
ECST-H	ECST-Hungarian
PSO	Particle Swarm Optimization
ABC	Artificial Bee Colony
VABC	Velocity added ABC
AVABC	Adaptive VABC

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I. INTRODUCTION

A distinctive large-scale WSN [1] [2] [3] includes numerous sensor nodes that are exploited randomly or based on certain predetermined arithmetic distribution over a geographical area of interest. The sensor node encompasses numerous resource factors like battery power, limited memory, communication abilities, computation and signal processing and thus, it could sense only a reduced area of the environment [4] [5]. In WSN, the sensors tend to convey the data to sensor nodes once the information is gathered from the surroundings [6] [7]. It is important to confirm that every device can interact via the gateways. Because of the multi-hop characteristic of WSNs, a "full connectivity of the network" is required for consistent information transmission. Usually, a network is said to be connected if every pair of nodes make communication with each other, either indirectly or directly [8] [9].

With the increase in the count of sensors in WSN, the cost also seems to be increased for the entire network. As a result, it is important to find out the least count of nodes required for a WSN to attain connectivity [10] [11] [12]. Numerous appliances on WSN [13] [14] are required to be carried out for certain tasks whose effectiveness could be computed based on coverage. In such appliances, it is necessary to portray the accurate measures of coverage and connectivity [15] [16] that cause an impact on the overall behavior of the system. Hence, for optimal sensor deployment in WSN, it is necessary to recognize varied CI [17] [18]. The Information in CI helps in the interaction among the sensors and thus it aids in taking decisions on intellectual performances for WSN optimization [19] [20]. Frequent researches have suggested numerous approaches for the improvement of environmental coverage and connectivity of WSN [12] [20]. However, many sensor placement techniques have not considered the CI for sensor deployment as well as optimization [22] [23]. Some strategies are entirely based on the geometrical concern, which is theoretically proven but the realistic applications of the schemes are still facing many drawbacks that have to be considered in the future works.

The major contribution of this paper is depicted below.

1. This paper contributes a novel effectual sensor deployment approach in the application of irrigation management system in the agriculture sector.
2. The data collector IoT devices are located over the field that helps to communicate with one another. The most important aspect in this approach is the TCOV and NCON of IoT device. The problem met up by the IoT is the device mobility, which includes more power consumption, thus reducing the life span of the network.
3. Further, the adopted scheme aims to resolve the NCON and TCOV issues using the ECST. In addition, for insisting the minimum movement of mobile sensors over the network, FI-WOA model is introduced.
4. At last, the presented ECST-WOA scheme is evaluated over traditional schemes and the outcomes are revealed.

The arrangement of the paper is given as: Section II analyzes the literature work. Section III describes the irrigation management system under WSN: a case study and section IV portrays the proposed solution for solving both TCOV and NCON problem. Further, section V illustrates the results and section VI concludes the paper.

II. LITERATURE REVIEW

A. *Related works*

In 2018, Wei *et al.* [1] have established BCBS sensor deployment scheme to manage the coverage issue in mobile WSNs. Accordingly, the most important concern of the established approach was to discover the optimal positions for sensors to tackle the coverage issues resourcefully. Finally, the investigational results were offered that revealed the efficiency of the established BCBS technique.

In 2018, Sharma *et al.* [2] have presented a novel method for the optimal placement of sensor nodes. Here, every succeeding approach was an improvement and modification of its basic method. The adopted schemes have exploited the results that were obtained based on the position of sensor nodes on their PLs. The presented scheme demonstrated the importance of virtual path and it also portrayed the technique deployed by a CG that assists to arrive at its PL. In addition, the presented scheme deployed a persistent method to maintain the path of a floating CG in the direction of the PL so as to handle with wind movements.

In 2015, Maher *et al.* [3] have suggested a scheme to cover up a sensing region by deploying reduced amount of WSN's while maintaining connectivity among the sensors. The issue was summarized to a 2D coverage issue by the presented scheme. From the analysis, it was found to offer the best solution for the entire coverage issues. Finally, it was revealed that the introduced technique performed better than several standard sensor deployment models.

In 2018, Hoang *et al.* [4] have introduced a scheme based on the connectivity of sensors in mobile WSN's in terms of path probability and node isolation. The implemented model has considered the impacts caused by ecological constraints such as soil composition and soil moisture, and system parameters like, propagation and density. Here, both quantitative and qualitative evaluations were offered to validate the efficiency of the presented model. Finally, the outcomes attained have revealed the betterment of the presented model in attaining better connectivity of sensors.

In 2016, Li *et al.* [5] have adopted a scheme to manage with the CMMSDP. Here, the adopted model have included two approaches. The initial model was CRMC and the subsequent one was the SRMC model. The initial approach was extracted from optimal conditions and it intends at arriving the local maximum. The second approach aims to minimize the computational difficulty with small changes in optimality. Accordingly, the complexity and optimality outcomes were derived for the two approaches.

In 2016, Khelil and Rachid [6] have established a localized and distributed procedure, termed as ESA model to develop TCOV and NCON in WSN. The established model runs at similar intervals and for each interval, the nodes travel toward new targets so as to offer better connectivity and coverage. At last, the simulation outcomes demonstrated the robustness of the adopted model and it has provided improved outcomes than other traditional approaches with respect to moving distance and coverage ratio.

In 2017, Sun *et al.* [7] have suggested an SPCCA in WSN for reducing the utilization of energy and to expand the life span of the network. Accordingly, the blind spot could be discarded and the energy balance could be maintained. At last, the duplicated nodes on the shortest path were formed to offer better assurance on the NCON. In addition, the simulation outcomes demonstrated that the count of functioning nodes of the adopted scheme was constant and they do not rise with the number of nodes. Furthermore, the presented approach has achieved improved outcomes than majority of conventional schemes with respect to TCOV, NCON and cost and life span.

In 2011, Wang and Liu [8] have deeply studied the deployment problem of the traffic relay node. Basically, it was considered that the deployment issue was a tedious task and they have faced many challenges, which have to lead to poorer performance. To overcome all these shortcomings, an improved algorithm was modeled for node assignments along with certain modifications, which have yielded more real-time solutions. The developed solutions were analyzed over conventional methods and the presented model was found to yield promising results.

B. *Review*

Table 1 portrays reviews on optimal sensor deployment in WSN. At first, BCBS was deployed in [1], which provides improved precision and better convergence. However, reduction in iteration count reduces the convergence. In addition, CG was presented in [2], which limits the pollution and it also positions the SN's accurately. Yet, it needs consideration to handle with high-intensity vortices. GA was employed in [3], which is highly efficient and it offers improved decision making, but there is no consideration on certain infrastructure factors. MI approach was exploited in [4] that attains reliable connectivity and reduced path loss. However, there exists an occurrence of varied plots. Moreover, CRMC was presented in [5], which reduces the complexity and offers better time cost. Still, it needs consideration on joint connectivity issues.

ESA model was deployed in [6], which provides better connection cost and increased life span; however, it requires more consideration on asynchronous mobile WSN. Also, SPCCA model was exploited in [7] that offer better robustness and it enhances the coverage. However, it requires consideration on asynchronous mobile WSN. Finally, Greedy algorithm was employed in [8], which grants optimal solutions with improved life time, anyhow, the real-time application is difficult. Such drawbacks should be regarded for enhancing the optimal sensor deployment in WSN in the present work.

TABLE I. FEATURES AND CHALLENGES OF OPTIMAL SENSOR DEPLOYMENT IN WSN USING VARIOUS TECHNIQUES

Author [citation]	Adopted methodology	Features	Challenges
Wei *et al.* [1]	BCBS approach	❖ Improved precision ❖ Better convergence	❖ Reduction in iteration count reduces the convergence
Sharma *et al.* [2]	CG model	❖ Limits the pollution. ❖ Positions the SN's accurately.	❖ Needs consideration to handle withhigh-intensity vortices
Maher *et al.* [3]	GA	❖ Highly efficient ❖ Improved decision making	❖ No consideration on certain infrastructure factors.
Hoang *et al.* [4]	MI	❖ Attains reliable connectivity ❖ Reduced path loss.	❖ There exists an occurrence of varied plots
Li *et al.* [5]	CRMC model	❖ Reduces the complexity. ❖ Better time cost.	❖ Needs consideration on joint connectivity issues.
Khelil and Rachid [6]	ESA model	❖ Better connection cost ❖ Increased life span	❖ Have to concern more on asynchronous mobile WSN.
Sun *et al.* [7]	SPCCA model	❖ Better robustness. ❖ Enhances the coverage	❖ Requires focus on rechargeable networks.
Wang and Liu [8]	Greedy algorithm	❖ Grants optimal solutions. ❖ Improved life time.	❖ Real-time application is difficult.

III. IRRIGATION MANAGEMENT SYSTEM UNDER WSN: A CASE STUDY

Nowadays, there is a raise in the exploitation of WSNs, particularly in irrigation management systems. In this research work, three case studies are surveyed on such deployments.

Case Study 1—"San Jose del Cabo, BCS, Mexico [27]" have portrayed the deployment and development of an automatic irrigation system that consists of a remote server, a gateway, and distributed WSN. The mission was planned for implementing a WSN system which has the capability of minimizing the water consumption. The WSN encompasses temperature sensors and soil moisture that are buried in the earth in order to measure the varying depths. The gateway node includes developed services that support both GPRS communications and ZigBee [28] [29]. In addition, it was provided with intellectual decision-making services namely, automatic irrigation activation depending on temperature values and soil moisture that goes beyond a specific predetermined threshold value. Moreover, this project deploys

a remote server, which helps in storing the entire information, and exhibiting the information in a GUI. The benefit of this model is its enhanced feature analysis in real-time data. The components used in this case study are described below.

- WSUs: Every WSU comprises of processing unit, application specific sensors, radio transceiver, and battery power. For saving energy, the micro-controller will be under sleep mode and a solar panel is connected with every WSU to boost up their batteries.
- WIU: The WIU behaves as the master node, and gathers data from WSUs with the "ZigBee approach". The entire information attained regarding temperature and soil moisture is distinguished with a predetermined threshold values, and subsequently, for an approximated period, the pumps gets activated. The attained data and irrigation associated information are stored in the attached solid state memory and are conveyed through GPRS to the remote server by means of the HTTP. Here, by using the electronic relays of "12 V DC, 40-A", the pumps are driven. The WIU is built up with a button to carry out manual irrigation and it also gets instructed to vary the irrigation scheduling from the remote server. In addition, 4 diverse IAs are measured such as "manual irrigation, predefined irrigation, and automated irrigation with soil moisture", where a sensor gets dropped lower than the threshold and one sensor goes beyond the previous threshold.
- Remote web server: The server demonstrates a particular GUI that envisages the information from every WSU, entire water utilization, and IA variety. The web appliance also facilitates the user with direct programming service and it also varies the values of threshold depending on the season and type of crop.

Case Study 2—"SSW": The SSW scheme presented by [30] has established a novel methodology for the SSW system which intends to measure the surface to depth soil moisture view of on-field sensors. The "University of Michigan Matthaei Botanical Gardens in Ann Arbor, Michigan" was selected for deploying the on-field sensors. For modeling the spatiotemporal deviations in soil moisture, the in situ sensors were exploited, which helps in facilitating the satellite surveillance of soil moisture in the future. For enhancing the energy preservation and for reducing the entire cost, the author has planned to model the sensor information in a sparse way.

The sensor web is lead by the intelligent control system that aims to find out an optimal sensor selection policy to make a decision on sensor configuration with respect to time. It also aimed to determine the estimation approach depending on the 3D soil moisture data. Accordingly, here the issue of determining an optimal approach and evaluating a constraint are designed by means of POMDP [31].

The system portrayal is given below.

- Ripple 1 system: At fixed locations, the on-field sensor nodes are deployed and they are built up with three to five soil moisture probes. The node communication is performed by means of the "ZigBee technology built on the IEEE 802.15.4 standard". The nodes were categorized into three parts, router, coordinator, and end devices. The node level constraints and sensors are provided in Table II.

TABLE II. DEPLOYMENT CONSTRAINTS

Constraints	Value
Soil moisture sensor	"ECH2O EC-5 (http://www.decagon.com/)"
Photovoltaic cell	"Solar panel 700-11347-00 (http:// www.sundancesolar.com/)"
ZigBee module	"XBee-PRO ZB (http://www.digi.com/)"
Electronic relay for pumps	12 V DC
System-on-chip	"EM-250 (https://www.silabs.com/)"
Architecture	"Multi-tier heterogeneous mesh"
Node battery	"HR-4UTG (http://www.sanyo.com/)"
Transmission range	<61600 m
No. of nodes	30
Coordinator–server communication	3G

The sensor nodes contain batteries and it also contains solar panels for recharging purpose. The coordinate node is connected to the BS computer.

- Web server: The data is updated to the server by BS by means of 3G network, whose card is mounted on the BS. The server stores the entire data, and the mobile or home user is capable to envisage the data in real-time, thus combining the whole system from the in situ sensors to the distant user.

Case Study 3—"Alfalfa Crop Irrigation Cut-off System" [32] have offered a cut-off system for automatic irrigation that intends to eliminate the tail water drainage in alfalfa crop. The work was done on the "UC Davis campus, California, USA", and here alfalfa remains to be the major water consumption crop. In previous days, the flood-irrigation technique was exploited for this crop. Anyhow, the water overflow minimizes the effectiveness of this technique. Hence, in [32], have developed a wireless sensor oriented system that offers irrigation data all over the field. Moreover, the system is realized by deploying a "water advance model" to the field exploitation of cellular communication and wetting-front sensors. The farmer gets a SMS that notifies the time to pack up the irrigation set up.

However, the balancing of both TCOV and NCON seems to be the most significant aspect that is to be rectified for attaining better communication and process. Both these issues are considered from this irrigation management case studies conducted in various areas. The below description explains the problem statement under these scenarios. Further, this paper also gives solutions for solving these problems with the involvement of optimization concepts as well. Fig. 1 demonstrates the optimal sensor deployment in IoT based WSN on irrigation management system. Consider an agricultural environment in which different sensors and BS's are deployed throughout the plot in different zones for automating the irrigation system. The architecture diagram symbolizes the problems related with TCOV and NCON. Therefore, it becomes necessary to solve the network and coverage issues for finding the optimal deployment of sensors in IoT. Hence, for solving the TCOV and NCON issues, the ECST based WOA model is deployed in the presented work that attains the minimum movement of mobile sensors over the network. The updated final location is again transmitted to the sensor nodes, from which the user can obtain accurate information regarding the location. In the similar way, each time, the location of the agricultural plot gets updated based upon the requirements of the user. Thus, this new aspect of sensor deployment task would produce the effective impacts in the irrigation management system.

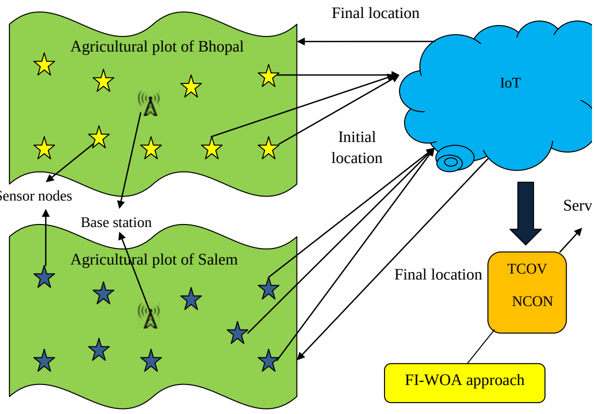

Fig. 1. Architectural representation of optimal sensor deployment in an irrigation plot

A. TCOV Problems

Assume a set of m targets with network region of n mobile sensors $T = \{t_1,..., t_n\}$ that are primarily positioned on a specified location. $L = \{l_1,..., l_m\}$ are positioned on identified locations that are to be enclosed. The below description enumerates the functioning of the system model.

(1) Via the GPS unit, each mobile sensor node recognizes its specific position in a network. In addition, the information on broadcasts movement order and sensors location are collected by sink.

(2) Assume the sensor movement in the specified area does not include any obstacles. If any obstacles are found in the network, the sensor chooses an appropriate path to the destination for avoiding the obstacles on the chosen path. So as to guarantee both NCON and TCOV in WSN, the movement of sensors should be detected carefully.

(3) Network model: Disk model [25] is considered for building an effectual communication among diverse sensors with radius z_c and target sensing with radius z_t. Every sensor and target could be covered up by numerous targets and sensors, correspondingly. The target is known to be

enclosed if at least a single sensor encircles the target with radius z_t.

Here, the circle surrounding the coverage disk is known as the "target's coverage circle" and the target's coverage disk is defined as a disk.

(4) Free Mobility model: In this model, the sensors are allowed to route or move successively in any direction and it also includes the capability to stop anywhere [26]. The energy utilization during the sensor movement is computed based on the traveled distance. The distance of sensor t to cover up target l is indicated by $dist(t,l)-z_t$, in which $dist(t,l)$ denotes the Euclidean distance among l and t. Likewise, the distance traveled to join sensor t_i with the sensor t_j is indicated by $dist(t_i,t_j)-z_c$, in which $dist(t_i,t_j)$ signifies the distance among diverse sensors t_i and t_j. In a perfect obstruction-free environment, the sensors have to travel along a path of straight line to arrive at the TCOV area for communicating the information among sink and coverage sensor nodes.

B. Problems on NCON

Each target in WSN is covered by at least one versatile sensor node after resolving the TCOV problem. In addition, another important issue on WSN is NCON problem that guarantees the data transmission by introducing the association among sink and coverage sensors. If the association among coverage sensors and sink is introduced primarily, then the NCON issue could be solved. On contrast, if there is no association among them, it is essential to analyze the NCON issue.

Definition 1: The NCON is a process of introducing connectivity among the coverage sensors and sink nodes that have enclosed the targets, by repositioning the rest nodes at least feasible movement.

In fact, the TCOV issue is resolved with a minimum of one coverage sensor node that encloses each target present in the WSN system. So as to prevail over the problems in NCON, the rest nodes that are randomly located should be repositioned with a slight movement and thus it could set up an association among coverage sensors and sink in WSN.

IV. PROPOSED SOLUTION FOR SOLVING BOTH TCOV AND NCON PROBLEM

The basic concept of NCON technique is to relocate the mobile sensor nodes to the optimal location such that it should be able to link with the sink to exchange information. Assume a tree topology that includes sink and coverage sensor nodes as root node and leaf nodes respectively. Here, the intention of NCON is to set up a reliable association among sink and coverage sensor nodes in WSN by making the rest nodes to move into a new location as connecting nodes, thus minimizing the cost of movement. According to the aim of NCON, it could be resolved in two phases.

In the initial phase, a "minimum edge length spanning tree topology" is constructed, where the length of edge among the sink and coverage sensors have to be minimum than communication radius, z_c. Usually, the MDST is necessary to reduce the rest node movements.

In the Second phase, the sink and coverage sensor nodes should be connected by means of the rest nodes as connecting nodes by repositioning the rest nodes to the produced Steiner points from ECST model. Anyway, it is an exceptional case of TCOV, where the rest nodes are enclosed with reduced distance to the Steiner points and Steiner points with zero coverage radius is performing as target. Therefore for every target, it is required to communicate efficiently with a dedicated sensor.

Steiner points of connectivity Determination: The vital role to resolve the problems in NCON is specified here: Building an edge length inhibited spanning tree L to connect the coverage sensor nodes and sink in WSN. As the Steiner tree issue is considered as NP-hard, an estimated model for NCON issue was formulated that comprises of: (1) generating an ECST, and (2) each successive edges of spanning tree is split with length lesser than z_c. Since the sum of the entire ECST edge length is minimal, the distance moved by the rest nodes for introducing the association among sink and coverage sensor nodes also gets reduced. The pseudo code of the ECST algorithm is given by Algorithm 1.

Algorithm 1.	The ECST Algorithm
Input:	$Z = z_1, z_2, \ldots\ldots z_n$; // The set of rest nodes
	T_{covzg} ; // The set of coverage sensor nodes
	$Sink(x, y)$; // The position of the sink
	z_c ; // The communication radius
Output:	sp ; // The set of Steiner points
	$N = T_{covzg}$;
	Produce a complete graph $H = (N, F)$;
	Generate an ECST L_{ecms} with sink and coverage sensor nodes as the root node of H and leaf nodes respectively;
	for each $n_i \in N$ and its parent n_p^i **do**
	Split the edge $h(n_i, n_p^i)$ into $\left\lceil \frac{\left\| e(n_i, n_p^i) \right\|}{z_c} \right\rceil$ parts;
	$sp(x_i, y_i) \leftarrow$ every splitting point;
	return sp ;

The subsequent stage is to assign the rest nodes to every point in sp produced from the ECST model's output with the reduced movement cost. As it is definitely an allotment problem, it could be solved by means of ECST-WOA algorithm. The pseudo code of ECST-WOA system to resolve the NCON issues is provided by Algorithm 2.

Algorithm 2.	The ECST-WOA Algorithm
Input:	$Z = z_1, z_2, \ldots\ldots z_n$; //
	$Sink(x, y)$; //
	T_{covzg} ; //
	z_c ; //
	ECST($Z, T_{covzg}, Sink(x, y), z_c$);

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2	WOA ($sp, Z / T_{covzg}$); // Moving Z to sp
3	**return** movement cost and deployment order

A. Relocation of Rest Nodes

The rest nodes are made to move for relocating the destination points following the determination of rest node's destination points. So as to enhance the minimal movement of rest nodes to link the sink and coverage sensors in WSN, FI-WOA algorithm is presented in this paper.

B. Solution Encoding

Consider the steiner point counts as N_{sp} and the randomly assigned count of rest nodes attained by ECST approach is indicated by N_{whale}. The solution for encoding is denoted by R_{ij}, in which $j = 1,2,..., N_{sp}$ and $i = 1,2,....., N_{whale}$. The encoded solutions R_{ij} are produced randomly by the rest node movement to the sp in the search space. Accordingly, the solutions that are encoded must be a real number in the $Z^{N_Z \times N_Z}$ search space which can be denoted by $R_{ij} \in [1, N_Z]$. In addition, the components in Z_{ij} have to be unique and thus it could be addressed as given by Eq. (1).

$$R_{i1} \neq R_{i2} \neq .... \neq R_{iN_{sp}} \qquad \forall i \tag{1}$$

Fitness Evaluation: The computation of fitness function takes place in terms of cost values among the steiner points and rest nodes as specified by Eq. (2), in which, $C[R_{ij}, j]$ indicates the cost function for moving the R_{ij} solution to j^{th} Steiner point. Fig. 2 shows the solution encoding of the presented model.

$$f_i = \sum_{j=1}^{N_{sp}} C_j \tag{2}$$

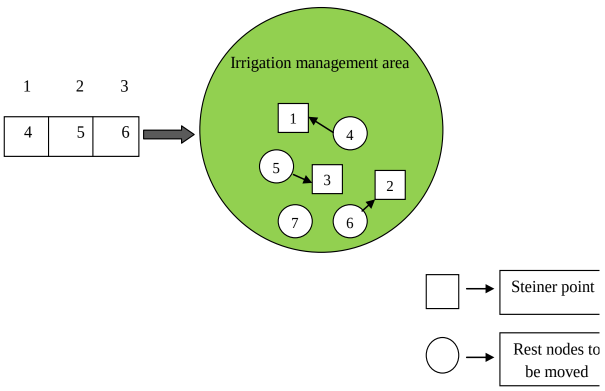


Fig. 2.Solution encoding.

C. Conventional Whale Optimization Algorithm

The most significant motivating property concerning the humpback whales [24] is the amazing process of hunting. They discover the prey's position and surround them. As the position of the best model in the search space is not recognized as a priori, this approach presumes that the current optimal solution is the targeted prey that is nearer to the best one. This behavior is denoted in Eq. (3) and Eq. (4), where it specifies the present iteration, $\vec{B}$ and $\vec{E}$ indicates the coefficient vectors and U^* symbolizes best solution attained till now, $|\;|$ points out the absolute value, and '$\cdot$' is an "element-by-element multiplication".

$$\vec{G} = \left|\vec{E}.\vec{U}^*(it) - \vec{U}(it)\right| \tag{3}$$

$$\vec{U}(it+1) = \vec{U}^*(it) - \vec{B}.\vec{G} \tag{4}$$

It is significant to observe that U^* has to be updated in the existence of a better solution. The vectors B and E are computed as specified in Eq. (5) and Eq. (6) and here $\vec{o}$ is minimized gradually from 2 to 0 for a set of iterations and $\vec{f}$ denotes the random vector between [0, 1].

$$\vec{B} = 2\vec{o}.\,\vec{f} - \vec{o} \tag{5}$$

$$\vec{E} = 2.\vec{f} \tag{6}$$

Exploitation phase: "*Shrinking encircling model*": This phase could be achieved by minimizing the value of $\vec{o}$ in Eq. (5). Note that the variation of $\vec{B}$ is lessened by $\vec{o}$ for varied iterations, i.e. $\vec{B}$ lies between $[-o, o]$ in which o is reduced from 2 to 0 for more iterations.

"Spiral updating position": Primarily, this scheme computes the distance positioned at (U, Y) and prey at (U^*, Y^*). A spiral formula is further produced among the location of prey and whale as in Eq. (7), in which $\vec{G} = \left|\vec{U}^*(it) - \vec{U}(it)\right|$ and it denotes the distance found between the i^{th} whale and prey, the constant for defining the spiral form is denoted by b and d is an alternate value lying in the interval between [−1,1]. Eq. (7) can be rewritten as in Eq. (8) in which u is a random integer lying among [0,1].

$$\vec{U}(it+1) = \vec{G}.e^{bd}.\cos(2\pi d) + \vec{U}^*(it) \tag{7}$$

$$\vec{U}(it+1) = \begin{cases} \vec{U}^*(it) - \vec{B}.\vec{G} & if \;\; u < 0.5 \\ \vec{G}'.e^{bd}.\cos(2\pi d) + \vec{U}^*(it) & if \;\; u \geq 0.5 \end{cases} \tag{8}$$

Exploration phase: Here, the search agent position is updated based on the arbitrarily selected search agent. It is portrayed as in Eq. (9) and Eq. (10), in which $\vec{U}_{rand}$ is an arbitrary whale chosen from the present population. The pseudo code of the conventional WOA is specified in Algorithm 1.

$$\vec{G} = \left|\vec{E}.\vec{U}_{rand} - \vec{U}\right| \tag{9}$$

$$\vec{U}(it+1) = \vec{U}_{rand} - \vec{B}.\vec{G} \tag{10}$$

Algorithm 3: Conventional WOA scheme [24]
Input: U_i
Output: U_i^*
U^* denotes best search agent
While $it < it_{\max}$
For all search agents

Update o, B, E, u *and* d
if 1 $u < 0.5$
if 2 $(|B| < 1)$
Update the position using Eq. (4)
else if 2 $(|B| \geq 1)$
Choose a random agent, $\vec{U}_{rand}$
Update the position based on Eq. (10).
end if 2
else if 1 $u \geq 0.5$
Update the position of present exploring agent based on Eq. (7)
end if 1
end for
Verify if the search agent exceeds the search space
Measure the fitness of search agent
if there exists an improved solution, update U^*
$it = it + 1$
end while
return U^*

D. Proposed FI-WOA model

Even though the WOA model does its excellent commitment in solving optimization crisis, it needs to be enhanced by means of convergence rate. Hence, to improve the performance of conventional WOA, the proposed method undergoes certain modifications as depicted here: In the conventional WOA approach, when $u \geq 0.5$, $\vec{U}(it+1)$is determined using Eq. (7), however, to improve the efficiency of optimal sensor deployment, in the proposed work, $\vec{U}(it+1)$is evaluated using Eq. (11). In Eq. (11), $C(fit)$ denotes the current fitness and $Max(fit)$ indicates the maximum fitness. With the new evaluation, the updating is performed. The pseudo code for the adopted FI-WOA scheme is specified by algorithm 4 and the flow chart is representation given by Fig. 3.

$$\vec{U}(it+1) = \vec{G}.e^{bd}.\frac{C(fit)}{Max(fit)} + \vec{U}^*(it) \tag{11}$$

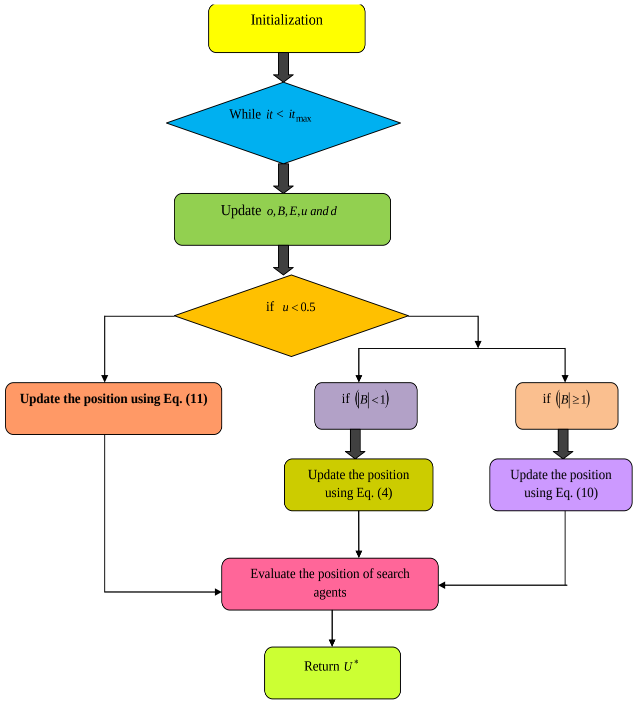


Fig. 3.Flow chart of the proposed model

Algorithm 4: Proposed FI-WOA model

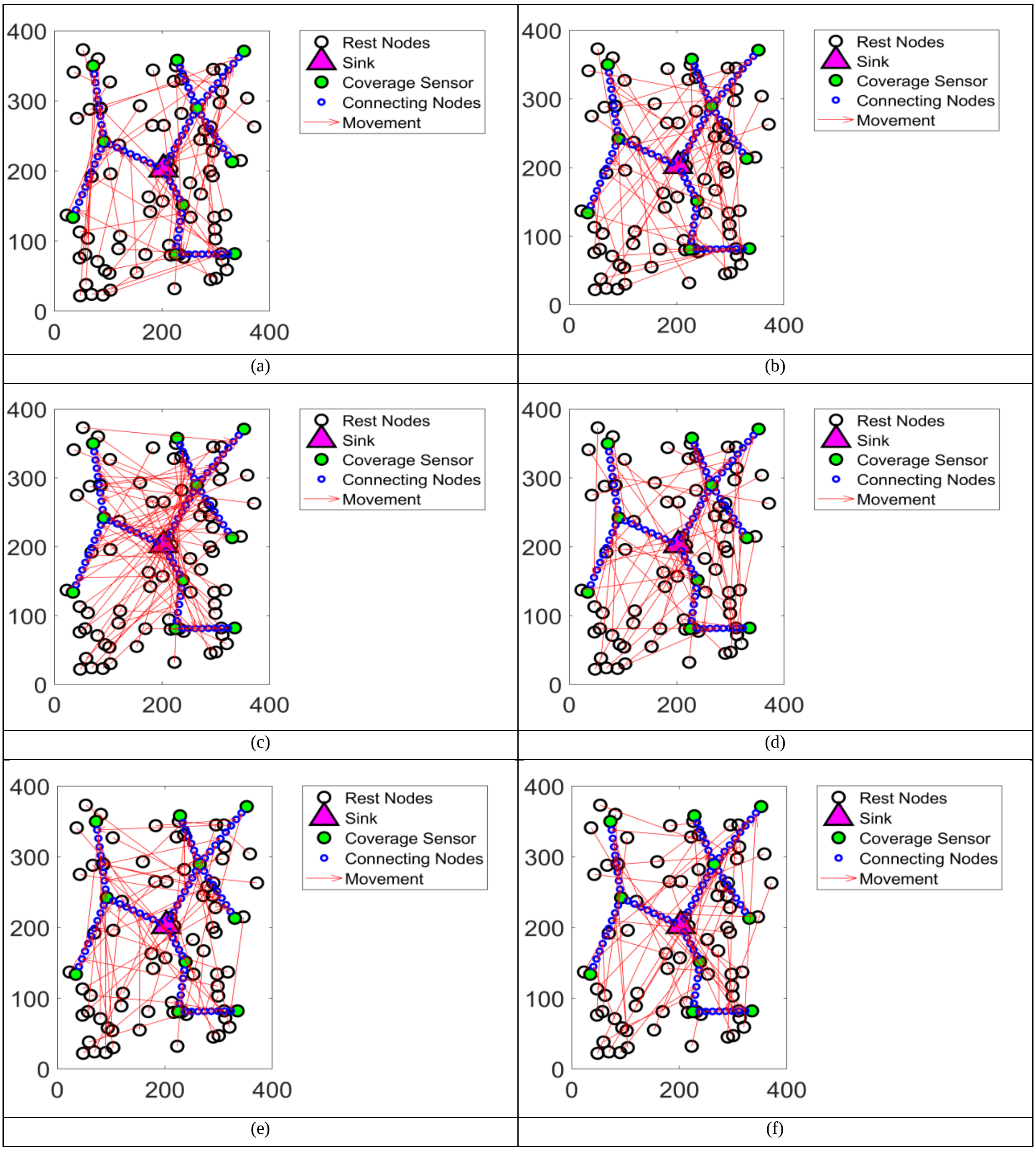
Input: U_i
Output: U_i^*
U^* denotes best search agent
While $it < it_{max}$
For all search agents
Update o, B, E, u *and* d
if 1 $u < 0.5$
if 2 $(|B| < 1)$
Update the position using Eq. (4)
else if 2 $(|B| \geq 1)$
Choose a random agent, $\vec{U}_{rand}$
Update the position based on Eq. (10).
end if 2
else if 1 $u \geq 0.5$
Update the position of present exploring agent with new evaluation as per Eq. (11)
end if 1
end for
Verify if the search agent exceeds the search space
Measure the fitness of search agent
if there exists an improved solution, update U^*
$it = it + 1$
end while
return U^*

V. RESULTS AND DISCUSSIONS

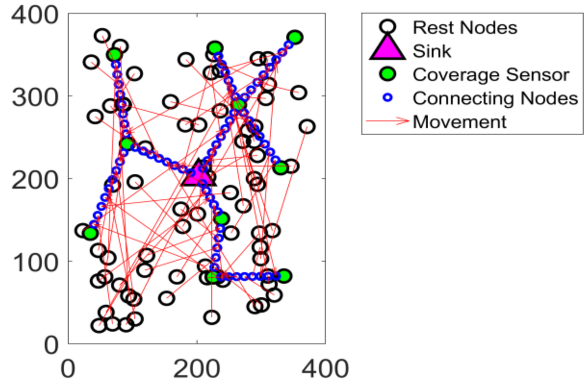
A. Simulation procedure

The adopted optimal sensor deployment in WSN using FI-WOA was performed in MATLAB 2018 a platform, and the results were observed. After execution, the performance of adopted FI-WOA model was computed over traditional models such as ECST-ABC

[32], ECST-AVABC [36], ECST-H [33], ECST-PSO [34], ECST-VABC [37] and ECST-WOA [35]. Here, the examination of movement distance was also performed with respect to the number of targets such as 10, 20, 30, 40 and 50 and sensing radius like 5, 10 and 15, respectively. Fig. 4 shows the simulation outcomes of optimal movement of rest nodes to act as the connecting nodes exhibited by various models.



(a) (b) (c) (d) (e) (f)

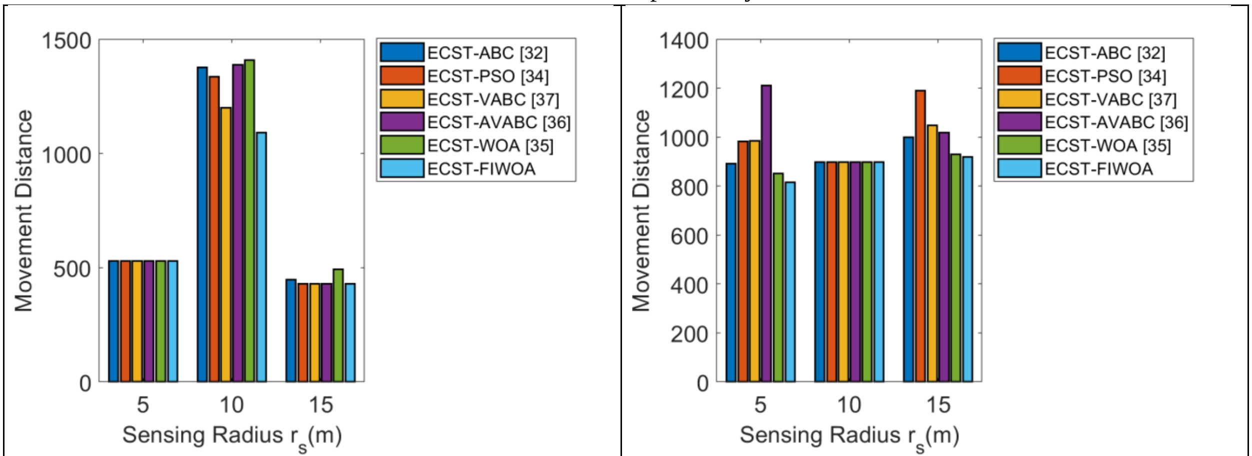


(g)

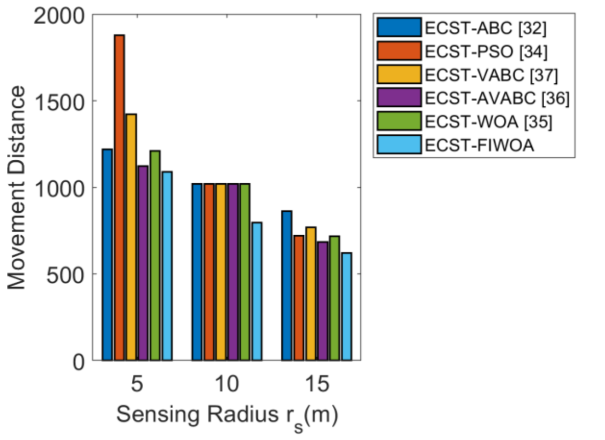
Fig. 4.Optimal movement of rest nodes to the connecting nodes along the coverage sensor using (a) ECST-ABC, (b) ECST-AVABC, (c) ECST-H, (d) ECST-PSO, (e) ECST-VABC (f) ECST-WOA and (g) FI-WOA.

B. Analysis on Target Coverage

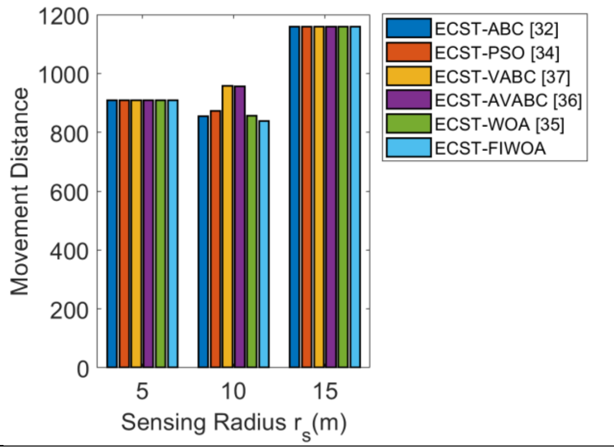
The analysis on TCOV for sensing radius of 5, 10 and 15 with respect to the number of targets such as 10, 20, 30, 40 and 50 is given by Fig. 5. From the outcomes, the presented FI-WOA approach has attained a reduced movement of distance with an increase in the sensing radius. From Fig. 5(a), the adopted scheme at 10th sensing radius is 16.67%, 12.5%, 8.33%, 16.67% and 20.83% better than ABC, PSO, V-VABC, A-VABC and WOA methods. In addition, from Fig. 5(b), at 5th sensing radius, the adopted FI-WOA scheme is 12.5%, 25%, 25%, 50% and 6.5% superior to ABC, PSO, V-VABC, A-VABC, and WOA methods. Also, from Fig. 5(c), the suggested scheme at 5th sensing radius is 13.64%, 72.73%, 27.27%, 9.1%, and 13.64% better than ABC, PSO, V-VABC, A-VABC and WOA models. Similarly, from Fig. 5(d), the presented scheme is 1.17%, 2.35%, 11.76%, 11.76% and 1.17% superior to ABC, PSO, V-VABC, A-VABC and WOA models. From Fig. 5(e), at 5th sensing radius, the adopted design is 6.89%, 6.89%, 6.89%, 6.89% and 6.89% superior to ABC, PSO, V-VABC, A-VABC and WOA methods. Thus, the superiority of the implemented FI-WOA model is proved by the simulation results.



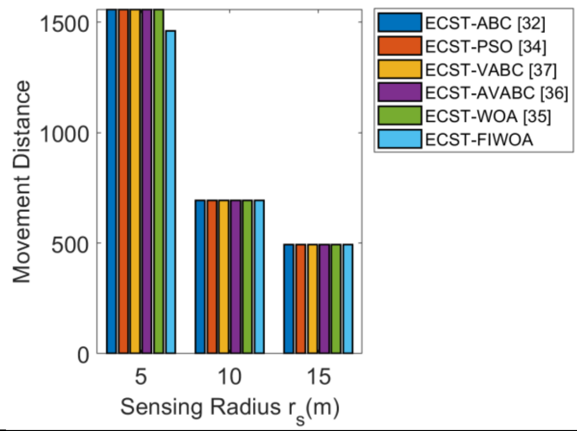
(a) (b)



(c)



(d)



(e)

Fig. 5.Analysis of TCOV for sensing radius of 5, 10 and 15 with respect to the number of targets such as (a) 10, (b) 20, (c) 30, (d) 40, (e) 50.

C. Analysis on Movement distance Vs Sensing Radius

Fig. 6 shows the analysis on movement distance with respect to sensing radius such as 5, 10 and 15. It is observed that the presented scheme have attained a minimal movement distance over the other schemes for all sensing radius. From Fig. 6(a), the adopted scheme at 10^{th} sensing radius is 31.67%, 28.33%, 15%, 28.33%, 28.33 and 15% better than ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA methods. Moreover, from Fig. 6(b), at 15^{th} sensing radius, the adopted FI-WOA scheme is 54.54%, 22.72%, 13.64%, 22.72%, 22.72% and 13.64% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA methods. Furthermore, from Fig. 6(c), the presented system at 15^{th} sensing radius is 29.81%, 5.59%, 5.59%, 5.59%, 11.27% and 11.27% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA models. Similarly, from Fig. 6(d), the presented scheme is 22.72%, 10%, 4.54%, 13.64%, and 13.64% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC and ECST-WOA models. From Fig. 6(e), at 15^{th} sensing radius, the implemented design is 70%, 12.5%, 12.5%, 12.5% and 12.5% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC and ECST-WOA methods. Therefore, the improvement of the presented FI-WOA scheme has been validated from the outcomes.

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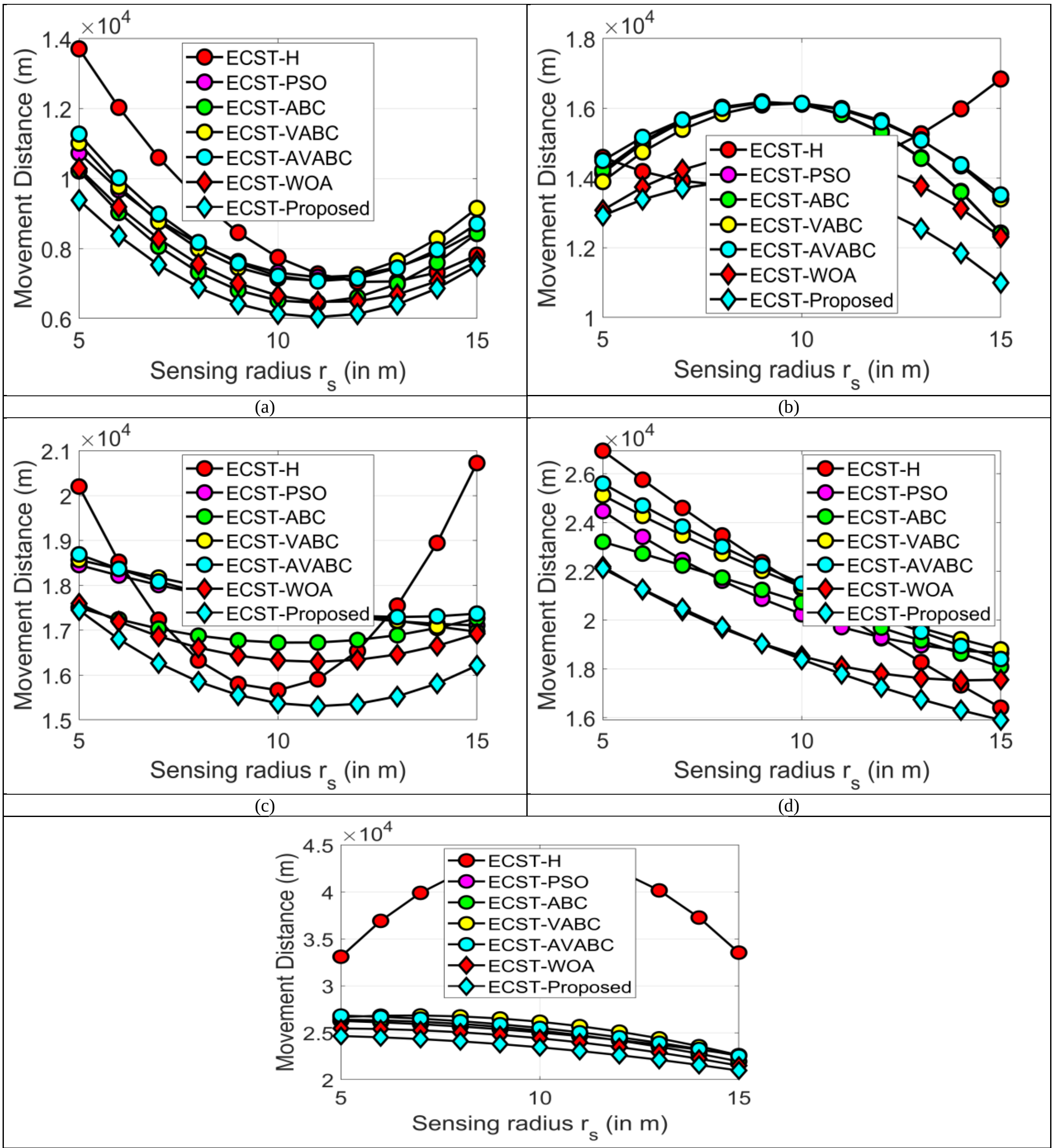
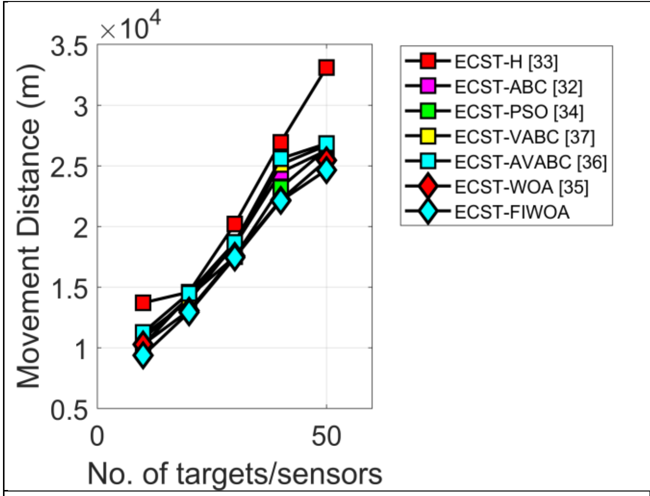


(a) (b) (c) (d) (e)

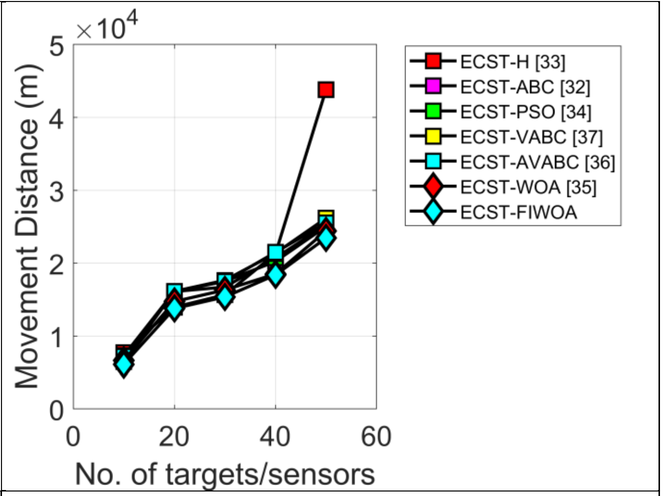
Fig. 6.Analysis on minimum distance for sensing radius of 5, 10 and 15 with respect to the number of targets such as (a) 10, (b) 20, (c) 30, (d) 40, (e) 50.

D. Analysis on Movement distance Vs Target sensors

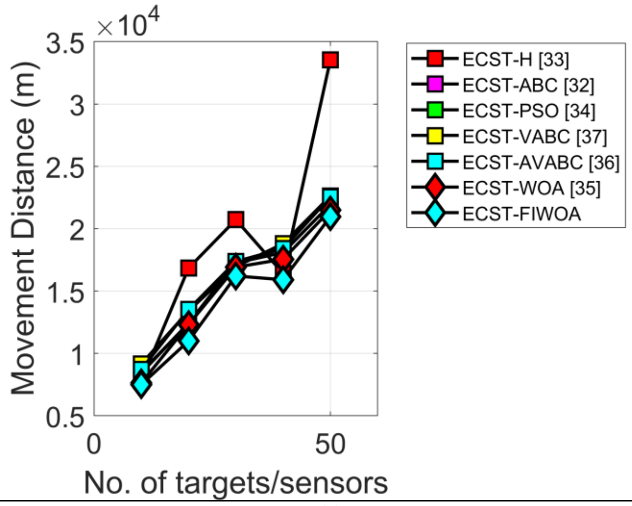
The analysis on movement distance with respect to the number of targets such as 10, 20, 30, 40 and 50 for sensing radius of 5, 10 and 15 is given by Fig. 7. From the attained outcomes, the implemented FI-WOA scheme was found to attain a minimal distance over the other compared schemes. From Fig. 7(a), the adopted scheme is 41.41%, 21.21%, 21.21%, 21.21%, 21.21% and 1.01% better than ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA methods when the number of targets is 10. In addition, from Fig. 7(b), the adopted FI-WOA scheme is 91.3%, 8.69%, 8.69%, 8.69%, 8.69% and 2.17% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA methods when the number of targets is 50. Also, from Fig. 7(c), the suggested scheme at 15^{th} sensing radius is 54.54%, 4.54%, 2.27%, 2.27%, 4.54% and 2.27% superior to ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA models when the number of targets is 50. Thus, the betterment of the adopted model is proved.



(a)



(b)



(c)

Fig. 7.Analysis on minimum distance for the number of targets such as 10, 20, 30, 40 and 50 with respect to sensing radius of (a) 5, (b) 10 and (c) 15

E. Mean and standard deviation Analysis

The analysis on mean(μ) and standard deviation (σ) for varying sensing radius for the presented scheme over the traditional models is demonstrated by Table III. On observing the attained results, the μ and σ of the presented model is found to be lesser for the entire varying sensing radius. From the analysis, at 5^{th} sensing radius, the μ of the adopted scheme is 13.45%, 45.27%, 17.22%, 7.2%, 19.41% and 8.41% superior to ECST-PSO, ECST-H, ECST-VABC, ECST-ABC, ECST-AVABC and ECST-WOA models. Likewise, the σ of the presented model is 22.65%, 47.41%, 40.29%, 20.88%, 26.12% and 20.77% better than ECST-PSO, ECST-H, ECST-VABC, ECST-ABC, ECST-AVABC and ECST-WOA schemes. On considering the 8^{th} sensing radius, the implemented scheme for μ is 18.14%, 37.15%, 16.61%, 6.44%, 18.42% and 9.99% superior to ECST-PSO, ECST-H, ECST-VABC, ECST-ABC, ECST-AVABC and ECST-WOA models. In addition, the σ of the suggested scheme is 51.46%, 72.14%, 45.91%, 36.1%, 66.03% and 38.76% better than ECST-PSO, ECST-H, ECST-VABC, ECST-ABC, ECST-AVABC and ECST-WOA schemes. Thus the improved performance of the implemented FI-WOA scheme was proved in a better way.

Fig. 8.Mean and standard deviation of the proposed and traditional schemes with respect to movement distance

Sensing radius	ECST- PSO		ECST-Hungarian		ECST- VABC		ECST- ABC		ECST-AVABC		ECST-WOA		FI-WOA	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
5	10721	296.63	13727	356.51	11076	339.3	10130	292.35	11283	305.03	10244	292.09	9449.3	241.85
6	9699.2	275.1	12084	331.06	9794.3	288.28	8979.4	214.7	10077	288.29	9222.2	283.69	8433.8	257.4
7	8789.2	291.93	10543	284.91	8769.1	233.82	8064.5	229.68	8966.8	287.11	8299.1	236.69	7507.6	208.96
8	8118.8	239	9425.1	271.63	8013.7	230.24	7314.5	214.75	8138.2	262	7559.3	218.96	6872.1	157.8
9	7608.6	216.37	8487.1	248.05	7451.3	203.7	6785.1	191.01	7575.9	237.34	6984.6	213.04	6425.2	182.85

10	7329.5	208.75	7776.8	226.4	7145.8	209.18	6531.2	184.91	7279.1	204.72	6658.6	202.49	6113.8	179.23
11	7177.1	214.08	7358	214.89	7128.8	188.34	6462.8	195.22	7093.9	199.04	6421.8	201.76	6055.4	166.76
12	7195.1	210.06	7072	207.96	7265.3	215.99	6574.1	218.36	7109.1	203.81	6505.8	180.88	6124.9	175.59
13	7435.7	236.44	7020.9	182.51	7616.9	251.66	6949.1	198.71	7468.9	213.79	6693.2	183.44	6398.9	185.49
14	7827.8	238.87	7304.5	230.97	8207.9	225.18	7622.4	245.8	7964.9	242.3	7044.5	215.85	6854.6	209.43
15	8488.9	233.69	7808.7	252.33	9210.5	241.98	8412.8	236.59	8716.2	248.93	7653.9	224.18	7505.5	211.34
μ - Mean, σ – Standard deviation														

VI. CONCLUSION

This paper has presented a novel effectual sensor deployment approach in the application of the irrigation management system in the agriculture sector. Accordingly, the data collector IoT devices were located over the field that helped to communicate with one another. The most important aspect in this approach was the TCOV and NCON of IoT device. The problem met up by the IoT was the device mobility, which included more power consumption, thus reducing the life span of the network. Further, the adopted scheme has aimed to resolve the NCON and TCOV issues using the ECST. In addition, for insisting the minimum movement of mobile sensors over the network, FI-WOA model was introduced. At last, the presented ECST-WOA scheme was evaluated over traditional schemes and the outcomes were revealed. On considering the TCOV, the adopted scheme at 10th sensing radius was 16.67%, 12.5%, 8.33%, 16.67%, and 20.83% better than ABC, PSO, V-VABC, A-VABC and WOA methods. In addition, on analyzing the movement distance with respect to sensing radius such as 5, 10 and 15, it was observed that the presented scheme have attained a minimal movement distance over the other schemes for all sensing radius. Also, the adopted scheme at 10^{th} sensing radius was 31.67%, 28.33%, 15%, 28.33%, 28.33 and 15% better than ECST-H, ECST-PSO, ECST-ABC, ECST-VABC, ECST-AVABC and ECST-WOA methods. Thus, the effectiveness of the implemented scheme has been confirmed.

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