# An efficient coverage and maximization of network lifetime in wireless sensor networks through metaheuristics

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**ABSTRACT**

In wireless sensor networks (WSNs), energy, connectivity, and coverage are the three most important constraints for guaranteed data forwarding from every sensor node to the base station. Due to continuous sensing and transmission tasks, the sensor nodes deplete more quickly and hence they seek the help of data forwarding nodes, called relay nodes. However, for a given set of sensor nodes, finding optimal locations to place relay nodes is a very challenging problem. Moreover, from the earlier studies, the relay node placement is defined as a non-deterministic polynomial tree hard (NP-Hard) problem. To solve this problem, we propose a multi-objective firefly algorithm-based relay node placement (MOFF-RNP) to deploy an optimal number of relay nodes while considering connectivity, coverage, and energy constraints. To achieve network lifetime, this work adopted energy harvesting capabilities to the sensor nodes and backup relay strategy such that every sensor node is always connected to at least one relay to forward the data. The optimal relay placement is formulated as an objective function and MOFF is applied to achieve a better solution. Extensive Simulations are carried out over the proposed model to validate the performance and the obtained results are compared with state-of-art methods).



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## 1. INTRODUCTION

In this paper, we have from past few years, wireless sensor networks (WSNs) have gained a huge interest in various fields like Industrial monitoring, home automation, forest and fire detection, environmental control, intensive agriculture, and among others [1]. Generally, the WSNs are composed of a group of sensor nodes (SNs) and a sink node (also can be called as base station). In WSNs, the main responsibility of SNs is to capture the information about the environment and the responsibility of sink is to accumulate the entire data from SNs. The SNs have some prominent features by which the WSN technology has gained a huge demand. For example, the SNs are cheap, small, autonomous power enabled and can capture several kinds of dataeven with same node. Mainly, the utilization of wireless technology has facilitated the network topology organization with very much less cost. These features have allowed the WSNs to deploy in environments where the wired technology is highly expensive or almost impossible [2].

Generally, the sensor nodes are battery operated devices which has limited lifespan due to the limited battery capacity. The entire information collected by SNs is forwarded to the sink node, consumes the energy resources of SNs. Moreover, this sensitive behavior of sensor nodes will affect the network performance. For example, if the topology of a network is assumedas start topology, and then all the senor nodes are assumed to have an equal energy distribution which is a very challenging issue. Even though various energy efficient mechanisms are derived, eventually the battery will drain out after a particular span of time [3]. A promising solution to this problem is making the SNs to harvest the required energy through some super capacitors and energy harvesters [4]. Instead of providing the required energy from external power supplies like batteries, if the sensor node's power supply unit is replaced with a renewable power generation unit (ex. solar panels), an increased network lifetime can be observed. With this strategy, the network lifetime can be increased up to some extent but the network demise is not avoidable, because the sensor node has to harvest energy in the doze off period. In the doze off period, the sensor node will harvest energy required for both information capturing and information transmission. Moreover, the time SN node to harvest energy is more than the time taken for depletion of energy. In such scenario, the SN is disconnected with other nodes, which makes the network to get demise. Hence there is a need to keep alternative nodes or back up nodes which takes the responsibility of doze off nodes which prevents the network from demising.

In WSNs, the SNs not only monitor and capture the information from environment, but also help to other senor nodes to forward the sensed data to sink node, which can be termed as relaying [5]. This type of multiple responsibilities (sensing and relaying) makes the sensor nodes to deplete more quickly. Generally, after sensing the information, sensor node goes into sleep mode to minimize the energy consumption, but due to the additional task of relying, they need to be awakened for all time. As a result, the senor nodes face additional computational tasks which results in faster energy depletion. Once the residual energy (RE) left at a SN is less than the energy threshold, then it will stop all tasks and moves into harvesting mode. Hence there is a need of responsibility distribution in which the entire nodes are grouped into two groups such as source senor nodes (SSNs) and relay nodes (RNs). The main responsibility of SSNs is to sense the information and the responsibility of RN is to forward the sensed data to sink node. However, the problem is to determineaproper number of RNs through which both network coverage and connectivity can be achieved along with less energy consumption.

From past few years, relay node placement (RNP) has gained a noteworthy research interest in the field of WSNs due to its effectiveness in achieving an improved network lifetime. In [6], the authors focused on two different deployments such as grid-based deployment and random deployment. In random deployment, the nodes are placed in a random manner and are structured in an AdHoc manner whereas in the grid deployment, the nodes are placed at the apexes of grid. Compared to the random deployment, the grid-based deployment has achieved more accurate positioning. Likewise, in [7], [8], a grid based RNP is modeled to connect the disjointed WSN segments by dividing the total area into equal-sized cells. The network size is optimized by the selection of an optimal cell count to be distributed by RNs such that all the segments are linked. However, this is considered as a "non-deterministic polynomial tree hard (NP-hard)" problem. Generally, to make the NP-Hard problem as a more realistic one, a two-layer procedure is employed [9], [10]. In these methods, the first layer is occupied by sensors in which they have to collect the information and transmit to the cluster head (CH) or RN. In this manner, the SNs will gain a less energy consumption rate as they will move into sleep mode immediately after the completion of data transmission to CH.

Recently, artificial intelligence has also been used for the optimization of network lifetime throughthe placement of optimal number of relay nodes at optimal locations. "genetic algorithm (GA)", "particle swarm optimization (PSO)", "artificial bee colony (ABC)", Firefly, "ant colony optimization (ACO)" etc., are some of the most common meaheuristic algorithms employed for the optimization problem. Khosrowshahi and Shakeri [11] addressed the RNP in a multiple disjoint network through GA. In this method, initially an upper bound of relay nodes is measured to set up the initial chromosome length. Next, the GA iteratively reduced the RNs count and discovers the optimal locations at the same time. Next, an improved version of GA, called as "genetic simulated annealing hybrid algorithm (GA-H-SA)" is considered by Yang *et al*. [12] to solve the relay node cover problem. This paper mainly focused over the optimization of three aspect such as energy consumption, number of relay nodes and connectivity. Next, focusing over the *k*-connectivity of the sensor nodes, Gupta *et al*. [13] developed two independent algorithms for RNP in which every SN will maintain at least *k*RNs. The first algorithm is based on GA and another one is based on Greedy mechanism. However, this approach focused over only the connectivity but not focused about the problem when the energy of a RN is depleted. George and Sharma [14] considered a modified version of GA for RNP in WSNs by following a "constrained RNP problem (CRNPP)"to reduce the RNs count while providing maximum connectivity.

Dandekar and Deshmuk [15] also focused on the*k*-connectivity of the sensor nodes and accomplished PSOthat places optimalRNs to achieve a required connectivity between the SNs of a homogeneous WSN. In this approach, the homogeneity is adopted by assuming that all the SNshave same range of communication. Xu *et al*. [16], the RNP problem is articulated as "steiner tree problem with minimum steiner points and bounded edge length (STP-MSPBEL)" which is NP-hard. Here, a variable meta-heuristic based PSO called as "multi-space (MSPSO)"is proposed to attain an optimal number of RNs.

In addition, some authors employed ABC algorithm also to solve the RNP problem. These approaches simultaneously focused over the *Q*-coverage and *K*-coverage scenario by which the network life and coverage are enhanced simultaneously [17]-[18]. Further, in [19], Liu and He aimed at the maximization of connectivity and minimization of cost incurred, and proposed a hybrid optimization algorithm called, ACO-Greedy. This approach especially focused on the Grid based networks. This approach is based on the ACO-Greedy through which the communication or sensing radius is dynamically adjusted to alleviate the energy hole issue and also prolong the Network Lifetime. Next, to lessen the deployment cost and also to recover the partitioned WSN, Sentukara *et al*. [20] proposed two distributed RNP methods based on Game theory and Virtual Force based relay movements.

Next, by combining the advantages of both ABC and PSO, an optimal RNP method is proposed by Mini *et al*. [21] which achieve an enhanced network lifetime with a pre-specified sensing range. Further, Lanza and Pulido [22] combined the ABC with Firefly algorithm to solve the RNP problem through multiple objectives. In this approach, totally three objectives such as network reliability (NR), average sensitivity Area (ASA) and average energy consumption (AEC) are considered and an optimized solution is derived through multi-objective ABC and multi-objective firefly algorithms. Unlike these methods which focus on theRNs placement, anenhanced RNs deployment method is proposed by Hamim *et al*. [23] based on ABC algorithm. This approach mainly focused on the extension of network lifetime with the deployment of optimal count RNs. This method has main focus on the extension of network lifetime through the optimization of network related parameters those are relatedto the constrained RNP problem.

Deployment of the SNs with energy harvesting capabilities is a new research direction in WSN which has more efficiency in network survivability and sustainability. Based on this inspiration, Misra *et al*. [24] focused to deploy minimum RNs at constrained locations, by guaranteeing that the RNs can harvest a huge volume of energy. For both issues, this approach had proven that the problem is NP-hard and solved through an algorithm based on polynomial time approximation. Next, as an extension, a “unified mixed integer linear program (MILP)” based RNP is developed by Misra *et al*. [25] to measure the lower range for the optimal solution of minimum RNP.

In this paper, we have proposed a new relay node placement strategy based on multiple objectives, called as multi-objective-oriented relay node placement (MORNP). MORNP totally considers three objectives such as energy, connectivity and coverage and the nodes which satisfy all these objectives are only chosen as relay nodes. The energy constraint is derived based on the novel relationship between energy harvesting rate and depletion rates of relay nodes. Next, the connectivity is ensured through the availability of paths to the sink node. The coverage is ensured based on the Euclidean distance between SSNs and RNs. Finally, this work also proposed a multi-objective firefly (MOFF) Algorithm to determine the optimal number of RN. Simulations are conducted over the proposed MORNP and the performance is measured through several performance metrics. Remaining paper is ordered as; the details of proposed MORNP are explored in section 2. Section 3 explores the details of simulation experiments and performance evaluation. Finally, the concluding remarks are given in section 4.

## 2. RESEARCH METHOD

### 2.1. Overview

In this paper, we have developed a novel optimization technique which reduces the number of relay nodes required to maintain an efficient connectivity and coverage in the WSN. This technique is a multi-objective-oriented relay node placement (MORNP) strategy based on firefly algorithm. Under this technique, we have considered three objectives such as energy, connectivity and coverage and accomplished multi-objective firefly algorithm to attain an optimal count of RNs. Moreover, this method also considered the problem of energy harvesting during the RNP. Under the energy harvesting problem, the RNs are assumed to have energy harvesting capabilities and for any source sensor node. This method derives at least one connected relay to the sink node during the doze off period of remaining relay nodes. Here, to ensure the energy constraint, we have developed a relation based on the harvesting rate and depletion rate of a relay node. Next, the coverage constraint is ensured based on the Euclidean distance between SSNs and RNs. Finally, the connectivity constraint is ensured by maintaining at least one path between any RN and sink node. Further the complete details of network model, energy constraint, connectivity constraint, coverage constraint, firefly algorithm are deliberated in the subsequent subsections.

### 2.2. Network model

In this paper, we have assumed a randomly deployed network with N number of SNs and only one sink B. Next, the SNs and RNs range of communication is assumed as *r* whereas for sink node, it is considered as R, where R>>r. In this model, the RNs are assumed to have energy harvesting capabilities.

During the data transmission, after particular span of time, if the energy level of any RN is reduced below the energy threshold, then that RN doze off (turns off all tasks such as transmitting and receiving) and energy harvesting starts. The RN will become active only after gaining sufficient amount of energy, called as Activation energy $A_E$. In this model, we have supposed that the SSNs and sink node placementis known to a prior. Further assumed that the process of energy harvesting is a stochastic one in which the rate of harvesting is varied with environmental conditions and hence it can also model as Spatio-Temporal Process. In the temporal model, the gain varies with different time instances where as in the spatial model, the gain is varied with different locations. Moreover, the energy harvesting rate is less than the energy depletion rate.

We have consideredonly one single sink node and its location is purely randomized. Further the locations of SNs are also randomized over a spatial location and let's let it be S. For any source node, if the sink node found to be located within its range of communication, then it forwards the sensed data directly. Otherwise, the source node seeks the help of any RN and forwards the sensed data through that RN. Two nodes A and B located at locations *i* and *j* can communicate only if the Euclidean distance between them is less than or equal to communication ranger as (1).

$$ED(A, B) \leq r \tag{1}$$

Where ED is the Euclidean distance and *r* is the range of communication. Simply the (1) states that the RNlocated at position *j* can help to the source node located at position *i*, to forward the data packets on satisfying that they have located at a distance which is less or equal to communication range *r* of node A. Next, the sink node is supposed to have an infinity power and it is associatedwith main power supply.

### 2.3. Energy constraint

For a WSN with larger network area, usually the most of the SNs can't lie inside the communication range of sink node. Hence the SNs not only perform the sensing task and also executes relaying task [5]. Under this, the sensor nodes work as relays and helps to the source sensor nodes to forward the data packets to the sink node. Due to these multiple responsibilities, all sensor nodes need to be awakening for almost all the time which results in faster energy depletion [29]. Hence the energy levels of SNs are dropped into the level below the energy threshold, which makes the nodes to drive into the mode of energy harvesting to procure sufficient energy. Thus, making the SNs to have energy harvesting capabilities can enhance the lifetime of network.

Proposed to develop an energy constraint assisted RNP. Here the energy constraint is defined with respect to two parameters such as harvesting rate and depletion rate. As already discussed, that the harvesting rate is always less than the depletion rate, i.e., the time taken for procuring the sufficient energy through energy harvesting is greater than the time taken for depleting the energy. This is due to the issue of both tasks such as transmitting and receiving. Compared to the depletion rate of relay node, the depletion rate of a source node is less due to the single responsibility. In this work, for energy harvesting model, we have followed the features of energy harvesting sensors [26] in which the sensor node will active only after gaining sufficient amount of energy. After gaining such amount of energy, it can be activation energy $A_E$, the relay node can spend and harvest simultaneously. Hence there exists a relationship between harvesting rate and depletion rate. Let $d_r$ be the depletion rate and $h_r$ be the harvesting rate, a relay node is formulated into three modes based on the relationship between $d_r$and $h_r$, as (2);

$$R_m = \begin{cases} d_r = h_r, Neutral\ Mode\ (N_m) \\ d_r < h_r, Saving\ Mode\ (S_m) \\ d_r > h_r, Deplting\ Mode\ (D_m) \end{cases} \tag{2}$$

Where $R_m$ is the relay mode.

Let$R_E$ be the residual energy left at a RN after particular span of time *t*, if it is less than the energy threshold $T_E$, then it stops all the communications and switches to the harvesting mode. During this mode the transceiver of RN is turned off. Once the RN has turned off the transceiver, the SSN cannot forward the data, by which the network becomes disconnected. Hence there is a need of backup RNs to perform the responsibilities of current disconnectedRN. However, the problem is to discover the locations at where the backup RNshave to place. One possible solution is to keep the backup RNs at the location approximately nearer to the departed RNs. However, it is not a viableanswer because there is no knowledge about the rate of harvesting of a particular location. Moreover, locating the backup RN at the same location of departed RN may causes serious effects like physical destruction, location damage, barriers, and shades. Moreover, the inaccurate prediction about the energy availability causes a serious effect over the lifetime of network, due to the unpredictable relationship between rat of depleting and rate of harvesting. As deliberated above, the energy harvesting from natural resources like wind, sun, heat and vibration is totally uncontrollable and unreliable. Hence the energy harvesting process can be modeled as Spatio-temporal process [27]. Further the energy harvesting process follows a periodic pattern [28] as the maximum energy is harvested in the day time and minimum energy is harvested in the night time. All these constraints make the RNP highly unstable. Hence this paper addresses the backup RNs which are independent of energy harvesting constraints and also to the energy obtainability of RNs in the future.

Under the energy constraint modelling, we have developed an efficient backup RN deployment method through which every SSN has an availability of ‘z’ backup relays in its neighborhood. The constraint to pick up the backup relay node is modeled as (3) and (4).

$$\frac{A_E}{h^P_{r(p)}} \leq \frac{1}{Q}\sum_{Q\in\boldsymbol{Q}} \frac{R^Q_{E(q)}}{d^Q_{r(q)}-h^Q_{r(q)}} \tag{3}$$

and

$$p = arg\,\min_{p}\left(\frac{R^p_{E(p)}}{d^P_{r(p)}-h^P_{r(p)}}\right), \forall\, p \in P \; and \; q \in Q \tag{4}$$

Where $h^P_{r(p)}$ is the harvesting rate of a relay node $p \in P$, $d^P_{r(p)}$ is the depletion rate of a relay node $p \in P$, $d^Q_{r(q)}$ is the depletion rate of a backup relay node $q \in Q$, $h^Q_{r(q)}$ is the harvesting rate of a backup relay node $q \in Q$ and $R^Q_{E(q)}$ is the residual energy of the backup relay node $q \in Q$. The constraint is (3) declares that the time consumed to gain a sufficient amount of energy such that the RN will get activeshould be less than the average provision time of short-lived RNs from all the remaining sets of RNs. Further, the constraint shown in (4) finds the short-lived RNs based on residual energy, harvesting rate and depletion rate. The shortest-lived RN $p \in P$ must harvest the enough amount of energy $A_E$ to get activate in the time the shortest-lived RNs of other relay sets $q \in Q$ get depleted. Thus, the SSNs would have always a RN to transfer the data to sink node. Through this constraint, the source sensor node keep connected to at least one relay node even though the ‘z-1’ relay nodes are moved to harvesting mode.

### 2.4. Connectivity constraint

In the WSN, most of the sensor nodes have no direct communication with sink. Hence, they will depend on the relay nodes to forward the sensed data. In the conventional relay node placement, if any relay node is disconnected due to reasons like limited energy, out of range communication, buffer overflow etc., the source node will get disconnected from the network. Hence the relay node needs to be positioned in such a manner that all the SSNs can found a communication link either through one relay or through set of relays. RN needs to be placed based on the several constraints and if not the deploying cost and maintenance overhead will be too high. Hence there is a need of an optimal RNs deployment to guarantee the connectivity. The major hurdle in the deployment is the total number of RNs to be positioned such that the network can achieve maximum connectivity. If less relay nodes are placed then there is a problem of connectivity, means all source sensor nodes are not covered. On the other hand, if a greater number of RNs are located, then there will be a problem of high deployment cost and also the huge maintenance overhead.

Hence, we developed an optimal RNP strategy which ensures a maximum connectivity with optimal number of RNs. For a given set of relays, the proposed method first discovers the possible pathsthen the relay node checks whether the sink is within the communication range or not. If it is found that the sink node is within the communication range, then the relay node connects to the sink directly. On the other hand, if the sink is found that it is not in the communication range butis in the communication range of neighbor relay node, then the current ray node establishes a link to the sink through the neighbor relay node. For instance, if we consider the path $i \rightarrow j \rightarrow B$, here *i* is the current relay node, *j* is the neighbor relay node and B is sink. To ensure the connectivity there will be at least one relay node which have a path to the sink either directly or through forwarding relays. The connectivity constraint is formulated as (5).

$$path = \; C_r \rightarrow N_r \rightarrow B, \forall\, C_r \in P \tag{5}$$

Where $C_r$ is the current relay node,$N_r$ is the neighbor relay node and B is the sink.
**Note:** to establish a connection between $C_r$and $N_r$, the Euclidean distance between $C_r$ and $N_r$ must be less than or equal to the communication range of each other.

### 2.5. Coverage constraint

The coverage constraint is defined as the maximum number of SNs those were covered by one RN. As the number of SNs increases covered by a RN, the total number of RNs to get deploy will get minimized. Here the coverage constraint is evaluated based on the Euclidean distance between the SNs and RNs. For a SSN,$s \in S$ and RN,$p \in P$, the coverage constraint is defined as (6);

$$ED(s,p) \leq r, \forall\, s \in S \text{ and } p \in P \tag{6}$$

The source sensor node $s$ can seek the help of a RN,$p$ when it is within the communications range. The coverage constraint shown in (6) denotes that every SN,$s \in S$ must be covered by at least one RN from each of 'z' relay sets. The demonstration of connectivity and coverage constraint is depicted as Figure 1.

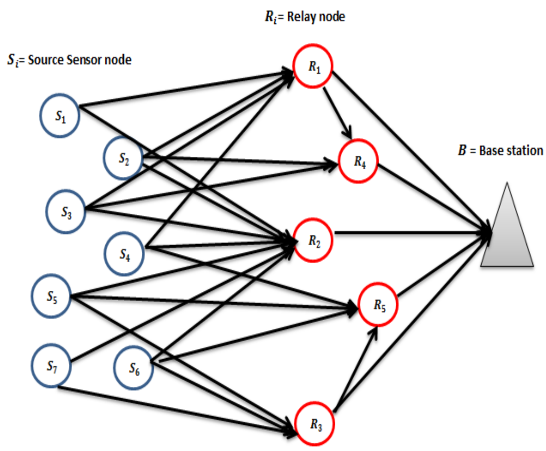


Figure 1. Connectivity and coverage constraint

As exposed in the Figure 1, the RN,1, $R_1$ covers four SSNs such as $S_1$, $S_2$, $S_3$ and $S_4$. Next the RN,2, $R_2$ covers five SSNs such as $S_1$, $S_2$, $S_3$, $S_4$, $S_5$, $S_6$and $S_7$.And, the RN,3, $R_3$ covers three SSNs such as $S_5$, $S_6$and $S_7$. RN,4, $R_4$ covers two SSNs such as $S_2$, and $S_3$. Finally, the RN,5, $R_5$ covers three SSNs such as $S_4$, $S_5$, and $S_6$. We noticed that the $R_2$ has maximum coverage and if we consider the $R_1$and $R_2$, then the total number of RNs required to cover the entire set of SSNsare 2. And, for every SSN there is an alternative relay node, for example, if SSN,3, $S_3$is disconnected with $R_1$, then the responsibility of data forwarding of $R_1$ is done with $R_2$. Similarly, if the $S_5$ is disconnected with $R_2$, then the responsibility of $R_2$ is taken by $R_3$ because the $S_5$is simultaneously connected with $R_3$. Hence the optimal number of RN sare 3, i.e.,$R_1$, $R_2$ and $R_3$.

### 2.6. Optimization of RNP by MOFF

In order to optimize the RNP, we have adopted MOFF. Since the firefly (FF) is simple metaheuristic algorithm with less computational complexity, we have considered it. With optimal number of RNs, the maximum connectivity is achieved with less energy consumption. Through the optimization, we will get an optimal number of RNs through which we can achieve maximum connectivity along with less energy consumption.

The FF is developed by Yang [30] based on the inspiration of fireflies idealized behavior. Generally, the fireflies produce a flash light to draw the attention of breeding partners and also for impending prey. The flash lights produced by fireflies are visible to only for limited distance. FF is constructed based on three rules:

(a) Entire fireflies are unisex, i.e., the fireflies draw the attention of other fireflies irrespective of sex.
(b) The attention of draw is relative to the intensity of flashlights produced by fireflies, i.e., for a given two fireflies, the firefly with less brightness is attracted towards the firefly which has high brightness.
(c) The variations in the light intensity are completely dependent on the quality of firefly.

Our main objective is to attain an optimal number of relay nodes based on three constraints such as energy, connectivity and coverage. Generally, in firefly algorithm, the firefly which has higher brightness is chosen as an optimal solution. Similarly in our work, the relay node is selected which can satisfy all the three constraints. For a given set of source sensor nodes, we have to derive an optimal number of RNs which have maximum connectivity and coverage. For this purpose, the objective function $f(z)$ defined as (7).

$$f(z) \rightarrow \min \sum_{p=1}^{P} |P_p| \quad (7)$$

Subjected to
*Energy constraint: (3) and (4)*
*Connectivity Constraint: (5)*
*Coverage Constraint: (6)*

Here 'z' denotes the set of minimum number of relays through which we can gain maximum coverage and connectivity followed by less energy consumption. Resembling with FF algorithm, attractiveness is related to Energy, Connectivity, and Coverage. Let $ED(A, B)$ be the Euclidean distance between sensor node A and relay node B in the solution space, given by (8)

$$ED(A, B) = \sqrt{(A_x - B_x)^2 + (A_y - B_y)^2} \quad (8)$$

Where $(A_x, A_y)$ be the co-ordinates of SSN, A and $(B_x, B_y)$ be the location coordinates of a RN, B. Grounded on this constraint, the next instance is formulated as (9):

$$f(x_j, y_j) = f(x_i, y_i) + \beta_0 e^{\gamma ED(A,B)^2} (A_j - B_j) + \alpha_t \quad (9)$$

Here $f(x_j, y_j)$ is the objective function at $j_{th}$ instant and $f(x_i, y_i)$ denotes the objective function at $i_{th}$ instant, $\beta_0$ is an initial distance (attractiveness) at ED = 0, $\gamma$ is the distance variation between $i$ and $j_{th}$ instants and $\alpha_t$ is a randomization parameter

## 3. RESULTS AND DISCUSSION

This section presentssimulation experiments conducted over the proposed model along with two conventional models. The simulations are carried outusing MATLAB and the comparative analysis is presented. This section includes simulation setup, performance evaluation through several performance metrics.

### 3.1. Simulation set up

In simulation set up we have created a random network with varying node count as N = [20, 30, 40, 50, and 60] and with different network areas, Area = $[300 \times 300, 500 \times 500, 700 \times 700, 900 \times 900, 1100 \times 1100]$ and the sink is placed at a random location. The transmission range of a sensor nodes is considered as one fourth of the network area, for example, if Area is $300 \times 300\ m^2$, then the communication range is kept as 75 m. The communication range of both senor node and relay nodes is assumed as same. To adopt the energy harvesting capabilities to the SNs, we have followed the energy distribution model explored in [31]. The details of simulation parameters are presented in Table 1.

Table 1. Simulation set up

| Parameter | Value |
|---|---|
| Number of nodes | [20, 30, 40, 50, and 60] |
| Network Area | $\begin{bmatrix} 300 \times 300, 500 \times 500, 700 \times 700, \\ 900 \times 900, 1100 \times 1100 \end{bmatrix}$ |
| Communication range | $1/4$ (Network Area) |
| Sink node location | Random |
| Data Rate | 125 kbps |
| Data type | Constant Bit Rate (CBR) |
| Energy threshold ($T_E$)) | 10% of initial energy |
| Activation Energy ($A_E$) | 75% of total energy capacity |
| Packet size | 512 bytes |
| Harvesting energy (mW)- Uniform | 0.3, 0.6, 0.9, 1.2, 1.5 |
| Harvesting energy (mW)- Random | 0.2, 0.4, 0.6, 0.9, 1.3 |

### 3.2. Performance metrics

The performance metrics we have considered are Total number of RNs, average energy consumption (AEC) and network lifetime (NL). The definitions of performance metrics are done as:

– Total number of relay nodes
  This metric is defined as the number of RNsessential to deploy in the network such that every SN will have at least one RN. Lesser the total number of RNs, better the performance.
– Network lifetime
  This metric is defined as the time taken by the process from the starting of a network to the time until any SSN is failed to send the data to the sink node. In this paper, the network is assumed to be disconnected when any of the SN is not connected to even one RN thereby it can't send the sensed data to sink. Higher the network lifetime, better the performance.
– Average energy consumption
  This metric is defined as the average amount of energy consumed by a node (both sensor and relay) to sense and forwards the data to sink node. Lesser the Average energy consumption, better the performance.

### 3.3. Results

In this section, we represent the particulars of performance metrics evaluated after the simulation of proposed model over varying network characteristics. Simultaneously, a detailed comparison of the proposed MOFF-RNP and conventional approaches. Under the conventional approaches, we have compared the MOFF-RNP with GA-RNP [13] and ABC-RNP [23]. Under the first case, we have varied the number of nodes and measured the total number of relay nodes and network lifetime. Under the second case, we have varied the network size and measured the total number of relay nodes and network lifetime. Under third case, we have varied the renewable power supply and measured the network lifetime and finally the average energy consumption is measured with varying number of RNs.

Figure 2 illustrates the details of total number of RNs deployed for varying number of SNs. From this figure, we can observe that the number of RNs increases gradually with an increase in the number of SNs. As the SSN count increases, they need more assistance (i.e., more umber of RNs) to forward the sensed data to the sink. After a particular level, it becomes constant because the entire network area has been covered by the deployed RNs and adding additional RNs consequences to more complexity. Next, the proposed MOFF-RNP is observed to have a smaller number of RNs compared to the conventional approaches at every count of SNs.

The GA-RNP and ABC-RNP require more relay nodes. In GA-RNP, the RNP is constrained to fixed positions and the placement is accomplished through Genetic Algorithm. GA-RNP didn't focus on the connectivity but not on the coverage and energy due to which there is a need of a greater number of RNs to cover the entire set of SSNs.Next, the ABC-RNP followed ABC algorithm for the selection of optimal locations of RNs by which the NL is maximized while the restrictions on cost and connectivity are fulfilled. However, this approach didn't focus on the energy depletion rate by which the additional RNs are required because the source sensor node will get disconnected if all the relay nodes are depleted. On an average the proposed approach has located 8 relay nodes while the ABC-RNP and GA-RNP located 16 and 19 relay nodes respectively. This result shows that the MOFF-RNP required only half of the relays of ABC-RNP and this great achievement is due to the energy harvesting capabilities of SNs.

In this work, the NL is defined by the time at which any of the SSN can't found a RN to connect. Figure 3 illustrates the details of NL for varying number of SNs. From this figure, we can observe that the network lifetime decreases gradually with an increase in the number of SNs. As the SSN count increases, the network results in more activities like packet retransmissions, synchronizations and communications between nodes by which the energy of nodes will get depleted faster rate. However, the proposed MOFF-RNP shows a more network lifetime compared to the conventional approaches.

In the conventional approaches, the relay nodes will not have energy harvesting capabilities and if their energy level is below the network will fail. Further, there is no back up off relay nodes and the source sensor nodes are disconnected completely.

The GA-RNP algorithm willnot ensure that every SN is covered by RN. Hence the performance is poor. In proposed method there exists always at least one backup RN for every SSN. Moreover, our approach ensures a guaranteed connectivity and never makes the SSNs to accomplish the RNs responsibility. Hence the network lifetime is more compared to the conventional approaches. On an average the proposed approach has a network lifetime of 10,600 minutes while the ABC-RNP and GA-RNP has 7,500 minutes and 6,300 minutes respectively.

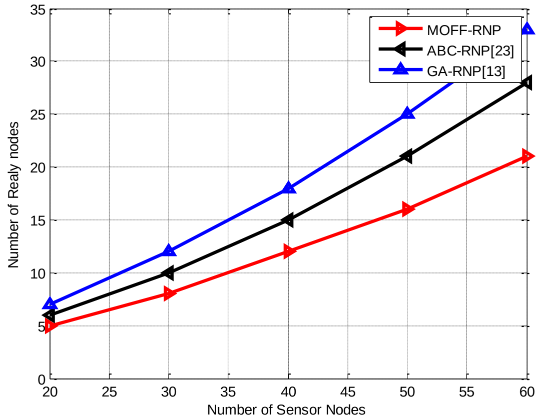


Figure 2. Number of relay nodes vs number of sensor nodes

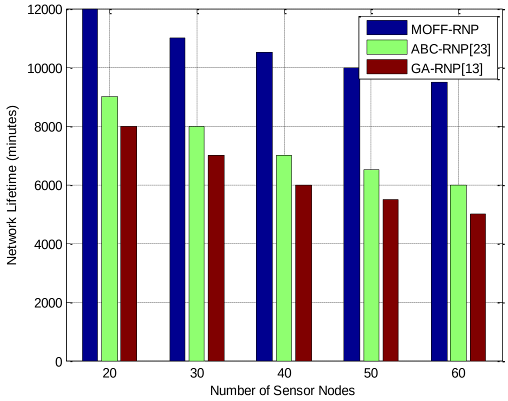


Figure 3. Network lifetime vs number of sensor nodes

Figure 4 describes the details of number of RNsobtained by the proposed and conventional approaches as a function of network size. From this, we can observe that the number of RNs increases gradually with an increase in the network size. For instance, in the above figure, the proposed approach requires 2 RNs for a network size of 700x700 whereas it was increased to 8 when the network size is increased to 1100x1100. As the network size increases, for a fixed communication range node, additional RNs are required to deploy for covering the entire area. Since the RN can cover only a fixed coverage area, the remaining area is covered by additional RNs. The proposed MOFF-RNP deployed a smaller number of RNs and the increment is also gradual. This reveals that the proposed approach has high coverage capability than the conventional approaches. Becauseit is simple; MOFF-RNP searches from the sink and deploys RNs such that every source node is connected to sink through either one or multiple RNs. This fact benefits to the proposed and hence the total number for RNs is less compared to the conventional approaches. On an average the proposed approach has located 4 RNs while the ABC-RNP and GA-RNP located 7 and 10 relay nodes respectively.

Figure 5 describes the details of network lifetime for varying network size. From this, we can observe that the network lifetime decreases gradually with an increase in the network size. In a network with smaller size, the relay nodes around the sink have less burden but in the case of network with larger size, the relay nodes around sink will suffer with great burden. In an elaborated way, the relay nodes nearer to the sink will carry the data packets of all nodes in the network thereby the energy will get depleted more quickly, resulting in anearly failure of the network. With small networks (i.e.,300x300) the GA-RNP has lifetime of 12500 minutes while for the larger networks (1100x1100) the lifetime is 6500 and it is approximately twice. On the other hand, the for small scale networks, the proposed approach has gained a network lifetime of 15,000 minutes while it is of 11,500 for large scale networks. This shows a greater scalability of the proposed MOFF-RNP.

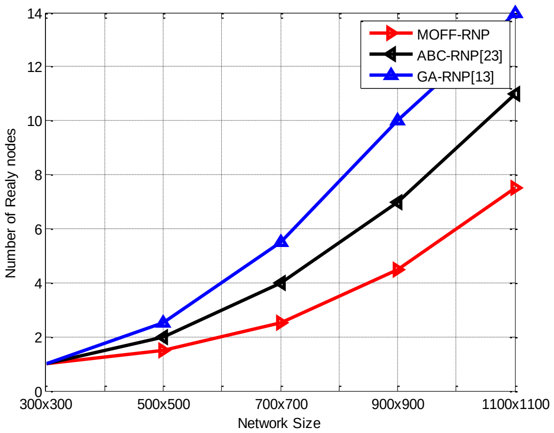


Figure 4 Number of RNs vs. network size

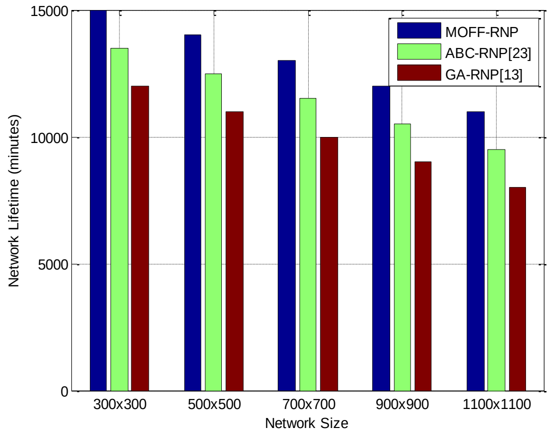


Figure 5 Network lifetime vs. network size

In the proposed model, the relay nodes are assumed to have energy harvesting capabilities and once their energy is below energy threshold, they will turn off all communication and moves into harvesting mode. In the harvesting mode, the relay nodes will harvest sufficient amount of energy and will get activate. In th simulation model, the harvesting energy is modeled with respect to time.

Figure 6 reveals the obtained network lifetime values after the simulation of proposed approach for constant supply of renewable incremental energy. In this case, we allocate supply a constant and incremental power supply and the network lifetime is measured. From the obtained results in Figure 6, we can observe that the proposed approach has gained a linear increment in the network lifetime. The linearity is due to the constant and same power supply in an incremental fashion. Furthermore, we can notice that the proposed approach has higher network lifetime than the conventional approaches. On an average the proposed approach has a network lifetime of 14000 minutes while the ABC-RNP and GA-RNP has 11000 minutes and 9000 minutes respectively.

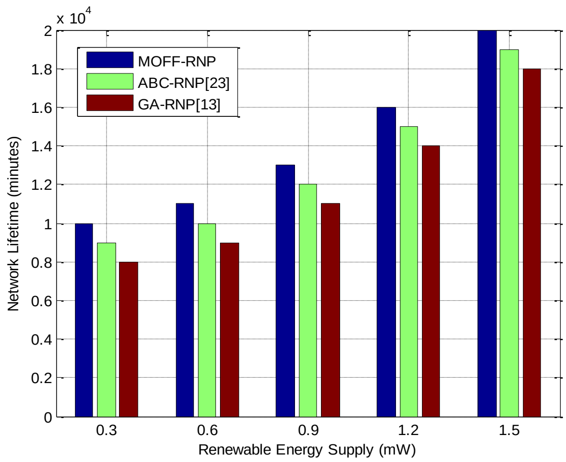


Figure 6. Network Lifetime vs. Constant Renewable power supply

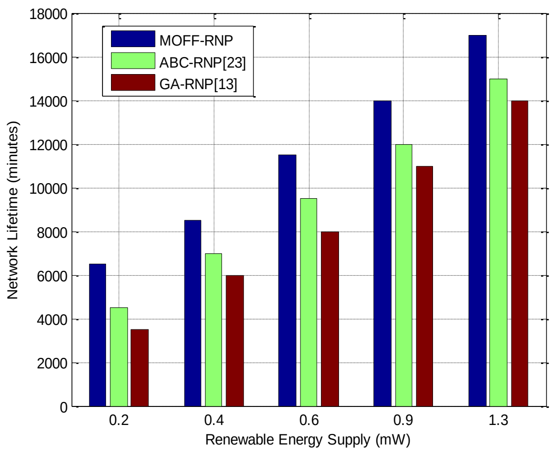


Figure 7. Network Lifetime vs. Random Renewable power supply

Unlike the above simulation, here we have simulated with random renewable power supply, the observed network lifetime is shown in Figure 7. In this simulation, initially the senor nodes are sated with random number of energies and also harvested random number of energies. From this figure, we can notice that the observed network lifetime through random renewable power supply is lesser than the network lifetime obtained through constant renewable power supply (as shown in Figure 6). For a detailed analysis, we have incremented the renewable power supply in random intervals. Initially it was increased by 0.2 mW and further it was increased by 0.3 mW and 0.4 mW and observed a maximum network lifetime of 16500 minutes (1.3 mW) whereas in the constant power supply it is of 20,000 minutes (at 1.5 mW). This is a more realistic one because in real time there is no possibility of constant power supply due to unpredictable and unreliable environments. On an average the proposed approach has a network lifetime of 11000 minutes while the ABC-RNP and GA-RNP has 9200 minutes and 8300 minutes respectively

## 4. CONCLUSION

This paper deals with the optimization of traditional WSNs by integrating the energy harvesting Relay Nodes. The central idea of this paper is to optimize three factors such as Average Energy Consumption, Connectivity and Coverage. This problem is noticed as NP-hard optimization from the earlier studies. However meta-heuristics are found fairly better performance towards such problems. Based on this inspiration, we have developed a Multi-Objective Firefly Algorithm based Relay Node Placement. In this algorithm, the sensor nodes are assumed to have an energy harvesting capability and also focused to maintain a set of backup relays always for every senor node. Further, this approach also considered connectivity and coverage constraints to attain an optimal number of relay nodes through which every sensor node will have a connection at any time. Finally, the optimal relay node placement is formulated as an objective function and solved through firefly algorithm. Through computer simulations we have proved that proposed method outperformed the state-of-art methods.

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