# A Fully Connected Cluster with Minimal Transmission Power for IoT Using Electrostatic Discharge Algorithm

**Mohammed A. Alanezi [1], Houssem R. E. H. Bouchekara [2,*], Muhammad. S. Javaid [2], and Mohammad S. Shahriar [2]**

[1] Computer Science and Engineering Technology
University of Hafr Al Batin, Hafr Al Batin 31991, Saudi Arabia

[2] Department of Electrical Engineering
University of Hafr Al Batin, Hafr Al Batin 31991, Saudi Arabia
*bouchekara.houssem@gmail.com

***Abstract* —** In the emerging age of the Internet of Things (IoT), energy-efficient and reliable connection among sensor nodes gain prime importance. Wireless engineers encounter a trade-off between sensors energy requirement and their reliable full connectivity. Consequently, the need to find the optimal solution draws the attention of many researchers. In this paper, the Electrostatic Discharge Algorithm (ESDA) is proposed, implemented, and applied to minimize energy needs of a sensor node while ensuring the fully-connectedness of each node. The obtained results show that the proposed method achieves better results than those found in the literature using the particle swarm optimization method in terms of energy savings and reliable connectivity.

***Index Terms* —** IoT, WSN, Network Power, Energy Saving.

## I. INTRODUCTION

Internet of Things (IoT) has emerged as an intrinsic part of modern lifestyle [1]. Things, objects, and devices that serve us on a day-to-day basis must effectively communicate to provide comfort without much human intervention. When it comes to nodal communication, energy efficiency is of prime importance. Therefore, strategies are to be devised to ensure that no energy is wasted during signal transmission and reception among various nodes. However, reduced transmission energy leads to connectivity issues. Thus, researchers have been trying to devise an optimal strategy since the last two decades, where nodes transmit signals with minimal power form a fully connected network [2]. Similar efforts are reported in [3] to reduce power usage in Wireless Local Area Network (WLAN) using energy-efficient antennas. Alternatively, harvested power can be wirelessly provided to the nodes fulfilling their power needs [4], [5]. Since new challenges appear in this field every day due to new networking protocols and interconnection of heterogeneous devices, the research is ongoing as discussed in [6].

Centralized connection algorithms experience limited efficiency due to increased communication overhead and added latency required to gather up and synchronise the flow of information from and to all coordinator nodes. However, a theoretical way to determine the optimal power requirements of these nodes is pivotal in exploiting the advantages of centralized systems. Providing full-area coverage with minimum energy requirements makes a centralized Wireless Sensor Network (WSN) control system a viable option with an added advantage of utilizing the central unit's high processing capabilities to make a well-informed decision. Additionally, the centralized hub for WSNs offers various networking benefits, including, optimal node localization and deployment, data aggregation, and energy-aware clustering [7]. Optimal localization of sensor nodes, otherwise, could have been a computationally-intensive process, as covered in [8].

Clustered WSNs promises extended network life. While designing simplistic networks of clustered topology, researchers generally consider the region without any obstacle [9]. Due to a rise in the need for wireless data collection, massive deployment of sensors at various locations is inevitable. This dense deployment of sensors, along with their independent nature, mount up a set of logistic challenges that inhibit their frequent recharging. Hence, energy efficiency becomes a crucial parameter to ensure reliability and longevity of a clustered WSN.

Communication overhead deteriorates network's reliability and energy efficiency. Data aggregation is a way to overcome the adverse effects of communication overhead, ultimately saving energy that would have been wasted otherwise in communicating with the far located

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base station [10]. For data aggregation, sensors operating in the near vicinity form a cluster, based on an efficient network organization algorithm. Each cluster is composed of member sensors and a coordinator, known as the headset, to coordinate with other clusters and base station, as shown in Fig. 1.

Reference [6] provides a survey focusing on control techniques and cluster selection to extend the battery lifetime of WSN. The topology control in WSNs, highlighting improved coverage, lifetime, and the reduced energy consumption is implemented in [11]. The selection of a neighboring cluster depends on energy reserve, node identifier and network density. A couple of surveys [12], [13] cover and classify clustering algorithms highlighting taxonomy of various clustering schemes. They provide a summary of classification algorithms based on constant convergence time algorithms and variable convergence time protocols. Their objectives, features and complexity are contrasted with each other while their performance is measured and compared on convergence rate, location awareness, cluster overlapping and stability, and node mobility within a cluster.

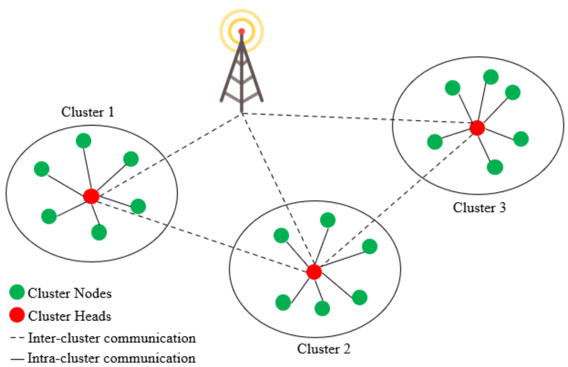


Fig. 1. Topology of clustered WSN.

This work focuses on the communications occurring within a single cluster. Electrostatic Discharge Algorithm (ESDA) is proposed to minimize energy consumptions by determining optimal transmission power while ensuring the fully-connectedness of the whole network. A comparison will be drawn with other commonly used metaheuristic optimization algorithms assessing the gain in energy-saving.

This remaining paper is organized as follows. Section 2 deals with problem formulation where the problem will be defined using a specific mathematical model and under due considerations. Once the foundation of the problem is established, Section 3 provides the details of the proposed optimization algorithm; ESDA. The section covers the step-by-step procedure of the entire algorithm. Next, in Section 4, the algorithm detailed in Section 3 will be applied to the problem of Section 2. Later, the obtained results will be explained. Section 5 concludes the paper and give some future recommendation.

## II. PROBLEM FORMULATION

The main objective of this work is to optimize the location of each sensor node in a WSN to ensure the minimum power handling at each node. The sensors at the edge of the network tend to connect with inward neighboring sensors while utilizing minimal transmission power. However, the sensors in-between the edges and the core tend to provide full connection outwards in all directions of the network. As the network grows, it becomes computationally impossible to check every possible location each sensor can take to ensure optimality. Hence, metaheuristic search techniques are employed to find the optimal solution. Sometimes, optimality is traded-off with the computational cost.

### A. System model

A single cluster comprising of $N$ wireless sensors is considered in this work, creating a mesh network. The objective is to transmit all measurement packets to a sink node. A square bounds the positions of both sink and sensor nodes. The global neighbor matrix $\Gamma$ is given by:

$$\Gamma_{ij}(\gamma) = \begin{cases} 0, \text{if } \rho_j < \rho_{th} \\ 1, \text{if } \rho_j \geq \rho_{th}, \end{cases} \quad (1)$$

where $\gamma_i$ denotes the transmitting power of node $i$, and $\rho_j$ represents power received at node $j$. $\rho_{th}$ is the measure of receiver sensitivity. Equation (1) indicates that the two nodes are connected if the signal is transmitted with enough paper such that the received power is higher than the receiver's sensitivity. Figure 2 represents the circular region of each node, where signal strength is strong enough to ensure connectivity. Therefore, at the boundary of each circle, the measured signal strength is $\rho_{th}$ and so any receiver inside this circular region will be able to receive the signal.

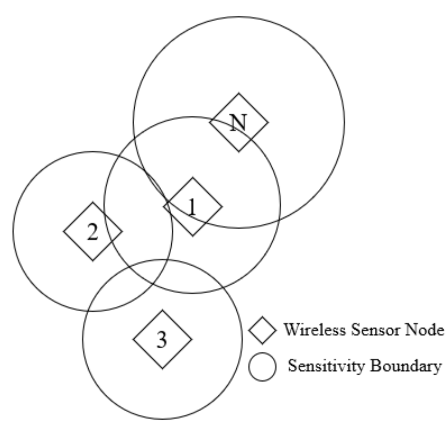


Fig. 2. System model.

The received signal power, $P_R$, depends on the transmitted power, $P_t$, and the distance of the receiver from the transmitter, $d$, as given below:

$$\frac{P_R}{P_t} = \frac{A_r A_t}{d^2 \lambda^2}, \quad (2)$$

where $A_r$, and $A_t$ represent the effective areas of receiving and transmitting antennas, respectively, and $\lambda$ denote the wavelength of the signal being transmitted. Equation (2) is also referred to as Friis Formula [14]. Since this work is not focused on sensors' antenna design, a single isotropic transmission and reception antenna at each sensor node is used to model the antenna's effective area, $A_{isotropic}$:

$$A_{isotropic} = \frac{\lambda^2}{4\pi}. \quad (3)$$

Therefore, if $A_{isotropic} = A_r = A_t$, (2) will be simplified to become:

$$\frac{P_R}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2. \quad (4)$$

Once the global neighbour matrix is calculated using (1), an algorithm determines if a pair of nodes is connected, as explained next.

### B. Ascertaining full connectivity

Full connectivity is defined as the scenario if each node has at least one active connection link, and all those links can form an unbroken path, as shown in Fig. 3 (a). When each node has one connection link but cannot be connected in a single path, a fake fully connected network is formed, shown in Fig. 3 (b). For networks with a few nodes, fully connectedness is quickly realizable and easy to check. However, in a real IoT application, due to many nodes, determining the associated connectedness becomes both computationally and visually challenging.

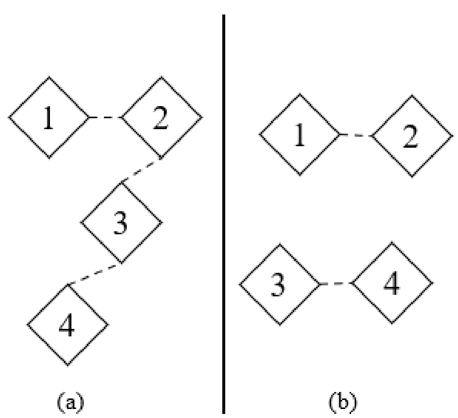


Fig. 3. (a) Fully connected network, and (b) disconnected network.

Calculating the Laplacian Matrix of the global neighbour matrix, $\Gamma$, is the first step in determining connectivity. If $n_i$ is the $i^{th}$ node, $n$ represents the total number of nodes, and $\deg(n_i)$ denotes the number of other nodes connected to $i^{th}$ node, $n_i$:

$$L = \left(l_{ij}\right)_{n \times n}, \quad (5)$$

$$l_{ij} = \begin{cases} \deg(n_i) & \text{if } i = j \\ -1 & \text{if } i \neq j \text{ and } \Gamma_{ij} = 1 \\ 0 & \text{otherwise} \end{cases}, \quad (6)$$

$$\deg(n_i) = (\Gamma^2)_{ij} \leftrightarrow i = j. \quad (7)$$

Equation (7) signifies that if $i = j$ then number of nodes connected to $i^{th}$ node is the same as the square of the neighbour matrix. After calculating the Laplacian Matrix, $L$, its eigen values, $\psi$, are computed using the equation below:

$$L.E = \psi.E, \quad (8)$$

where $E$ is $n \times 1$ eigenvector satisfying (8). Each eigenvalue $\varphi$ can be grouped to form a vector $\Psi$, as shown below:

$$\Psi = [\psi_1, \psi_2, \psi_3, \ldots, \psi_n]^t. \quad (9)$$

Here essentially, $\psi_1 < \psi_2 < \psi_3 < \cdots < \psi_n$ indicating that $\psi_2$, the second smallest eigenvalue must be positive in order to achieve a fully-connected condition. $\psi_2$ is also known as algebraic connectivity of $\Gamma$. Hence, observing the second smallest Laplacian eigenvalue of the neighbour matrix and verifying that there exists at least one connection for every node, determine if the network is fully connected. These conditions would ensure that transmission power is sufficient to establish a fully connected network.

## III. PROPOSED ALGORITHM FOR PROBLEM SOLUTION

As aforesaid, the ESDA is used in this paper to solve the problem of optimal energy saving in a clustered WSN by calculating power transmission of sensors and keeping all of them connected. The ESDA, proposed in [15], is a competitive optimization algorithm, and it is inspired by the electrostatic discharge (ESD) event. More details about this algorithm are given in the following subsections.

### A. ESD definitions

The advancement of solid-state electronics has revealed several concerning ESD issues in the design of the modern electronic system. Being a natural phenomenon, ESD has been discussed widely in numerous research articles, addressing the pros and cons [16]. A number of important definitions are presented in [17] where the ESD is presented as the abrupt transfer of charged particles between different electrostatic potential bodies.

The paper addresses the ESD event as an interval of electromagnetic fields, ESD current and corona effects at the time of ESD and before that. It defines the electronic equipment which got affected by an ESD event as equipment victim. The victim experiences the stress generated by ESD, and it may belong to the receptors or the intruders.

### B. ESD basic working principle

The conductivity of the materials varies from one to another. It affects the ability to contain charged particles. Some materials can accumulate positive charge quickly (like animal fur or human skin) whereas materials like plastic cups hold the negative charges effortlessly [18]. There are two approaches that an ESD may occur:

- Direct approach: when a moving object, also known as intruder, approaches to a stationary object (receptor) and transfer the charges. In such a case, intruder or receptor, anyone can be the equipment victim (Fig. 4).
- Indirect approach: where a third party sensitive object around the intruder and receptor gets affected by the electromagnetic field and thus becomes the victim (Fig. 5) [17].

While flowing through an integrated circuit, ESD current often passes through some PN junction paths, apart from the main least resistive channel. This may cause some degrees of unexpected dissipation. Moreover, it may result in some thermal damages to the neighbouring zones. Thus, repeated occurrence of ESD event inadequately affects the device and thus leads the system to malfunction [18].

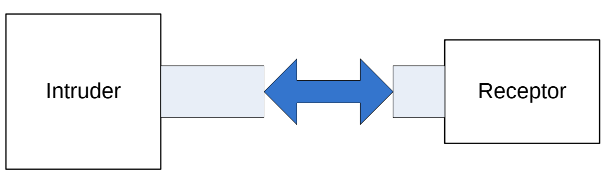


Fig. 4. Direct ESD event.

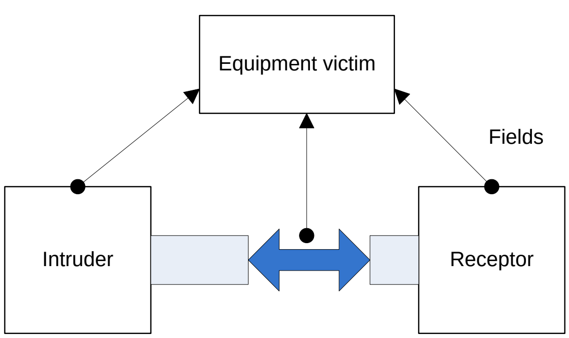


Fig. 5. Indirect ESD event.

### C. ESDA steps

The steps of the proposed algorithm are explained below in details and then summarized in Fig. 6.

**STEP 1:** Like genetic algorithm or similar heuristic optimization approaches, ESDA also generates a number of a random population of ‘ObjectsSize’ objects in its initialization stage. These generated objects are the electrical equipment, made of design variables like various components. In the given search space, the position of special equipment is analyzed to calculate its fitness value, which reflects the immunity of the equipment. Besides, a counter counts the number of times each equipment becomes a victim.

**STEP 2:** The proposed ESD algorithm iterates for ‘MaxIter’ times in this stage to solve the assigned optimization problem. Each iteration randomly selects three objects in descending order, keeping the best one in the first position. Instead of three objects, the same operation occurs between two if the randomly generated number ‘$r_1$’ appears to be higher than the predetermined value (0.5 in this case). In such a case of two-object involvement, the object with lower fitness value proceed to another one (with higher fitness) by following the rule:

$$\boldsymbol{x_{2_{new}}} = \boldsymbol{x_2} + \boldsymbol{2} \cdot \boldsymbol{\beta_1} \cdot (\boldsymbol{x_1} - \boldsymbol{x_2}), \tag{1}$$

where object 1 has better fitness than object 2, and their previous positions are denoted by $x_1$ and $x_2$, respectively. The object with the lower value will get the newer position ($x_{2_{new}}$) where $\beta_1$ is a randomly generated number with a normal distribution. It has the mean parameter (μ) of 0.7 and a standard deviation (σ) of 0.2. The mentioned case between two objects is an example of direct ESD event.

If the value of $r_1$ is found lower than the predetermined value 0.5, three objects will join in ESD operation. If the third object moves toward the other two, it will follow the rule mentioned below:

$$\boldsymbol{x_{3_{new}}} = \boldsymbol{x_3} + \boldsymbol{2} \cdot \boldsymbol{\beta_2} \cdot (\boldsymbol{x_1} - \boldsymbol{x_3}) + \boldsymbol{2} \cdot \boldsymbol{\beta_3} \cdot (\boldsymbol{x_2} - \boldsymbol{x_3}), \tag{2}$$

where the random numbers $\beta_2$ and $\beta_3$ are generated with the same standard deviation and mean parameter like $\beta_1$. Thus, the indirect ESD incident occurs where the object 3 got exposed to the electromagnetic fields of discharge and becomes the victim of the event.

In every step of ESD event occurrence, the counter gets incremented by one for the participant object.

**STEP 3:** This step checks the bound imposed over the objects, whether any of them appears outside of the search space or not. If found such, it brings it back to the required region.

**STEP 4:** This step checks all the objects one by one, to find whether any of them has gone through the ESD process for at least 3 times or not. Any such object is considered destroyed and a randomly generated new object will replace that within the search space. With less than three times of ESD occurrence, remaining objects will be assigned with the random number $r_2$ each. The objects with $r_2 > 0.2$ are also considered destroyed and subjected to the replacement procedure. Other components are marked as safe and kept for further operations.

**Inputs** ObjFunction (objective function), ProblemSize (dimension of the problem), LB (lower bounds), UB upper bounds, ObjectsSize (number of objects), and MaxIter (maximum number of iterations)
**Output** $X_{best}$, $F_{best}$ and $FunctionEvolution_{best}$
Initialization
**for** Iter=1: MaxIter
  **for** i=1: round(ObjectsSize/3)
    Select three objects randomly from the population of objects
    $r_1$=rand(0,1)
    **if** $r_1$>0.5
      $x_{2_{new}} = x_2 + 2 \cdot \beta_1 \cdot (x_1 - x_2)$
      $x_{2\ \mathrm{ESDcounter}} = x_{2\ \mathrm{ESDcounter}} + 1$
    **else**
      $x_{3_{new}} = x_3 + 2 \cdot \beta_2 \cdot (x_1 - x_3) + 2 \cdot \beta_3 \cdot (x_2 - x_3)$
      $x_{3\ \mathrm{ESDcounter}} = x_{3\ \mathrm{ESDcounter}} + 1$
    **end if**
  **end for**
  Check if there are objects outside the search space
  **for** $i_1$=1: ObjectsSize
    **if** $x_{i_1\ \mathrm{ESDcounter}} \leq 3$
      **for** $i_2$=1: ProblemSize
        $r_2$=rand(0,1)
        **if** $r_2$>0.2
          A component must be changed
        **end if**
      **end for**
    **Else**
      The equipment must be changed
      $x_{i1} = LB + rand \cdot (UB - LB)$
  **end for**
Select the new population from the old and the archived ones
**end for**

Fig. 6. Pseudocode of the ESDA.

**STEP 5:** This step updates the archive by saving the fit population into the old. The elements of the archive are sorted carefully in best-to-worse order. Finally, the number of objects equal to ObjectsSize is selected from the top of the list, for the next iteration.

## IV. APPLICATION AND RESULTS

For the experiments, minimum transmission power as -30 [dBm] has been selected. The maximum power is determined to provide a connection for the largest possible distance of 28.284 [m] inside the area for random distribution, whereas the transmission frequency has been chosen to give the worst possible attenuation considering the frequency range of 915 [MHz], as typically used in WSN applications. Finally, the sensitivity defined as the lowest received power that allows information recovery is chosen to be -60 [dBm]. All the parameters used in this study are given in Table 1.

In order to compare our proposed approach using the ESDA, it has been applied to the same scenarios investigated in [19]. In that paper, there were six scenarios, in each scenario, there are 20 sensors spread in a square region defined by (20 [m] x 20 [m]) as shown in Fig. 7. The used algorithms were the Particle Swarm Optimization (PSO) and a simplistic method. For further comparison, other well-known algorithms like Genetic Algorithm (GA), Differential Evolution (DE), Black Hole (BH) algorithm, Electromagnetism-like algorithm (EM), Salp Swarm Algorithm (SSA) and Sine Cosine Algorithm (SCA) have been tested. It is worth mentioning that the real number of scenarios investigated in [19] is 10. However, after an in-depth analysis, it has been found that scenarios 1 and 3 are the same, scenarios 2 and 5 are identical, scenarios 4 and 6 are same, and scenarios 7 and 9 are same. Therefore, the number of scenarios has been reduced from 10 to 6 in this paper.

Table 1: Simulation parameters used in this work [19]

| **Parameter (Notation)** | **Value [Unit]** |
|---|---|
| Number of sensor nodes | 20 |
| Sensors transmission power range | -30 [dBm] |
| Sensor Transmission frequency ($f$) | 915 [MHz] |
| Area for sensors random locations (L x L) | 20 [m] x 20 [m] |
| Sensor sensitivity ($\rho_{th}$) | -60 [dBm] |

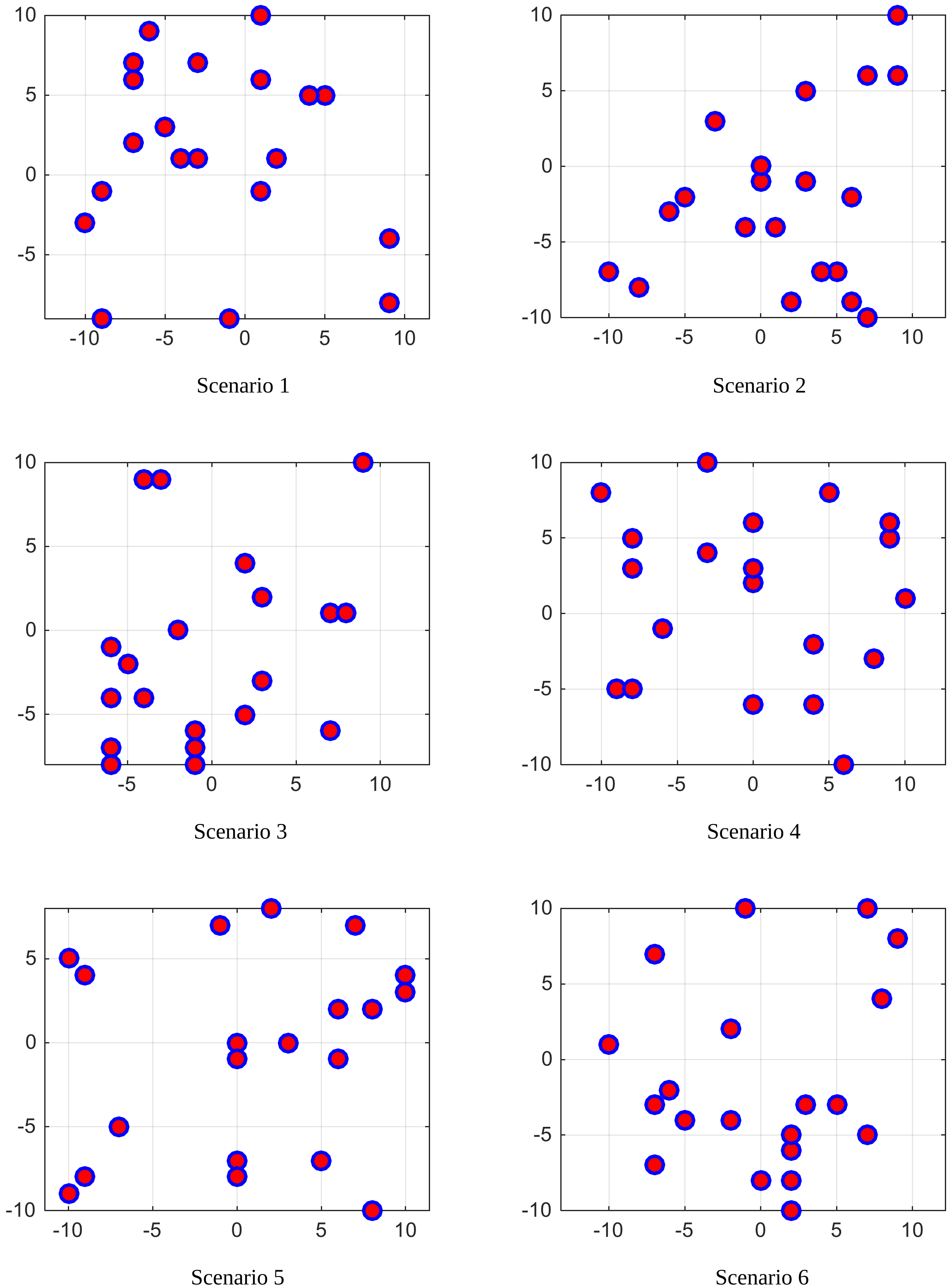


Fig. 7. The 6 investigated scenarios in [19] with 20 sensors spread in a square region with (20 [m] x 20 [m]) dimensions.

For a fair comparison, five runs have been performed for each scenario, and the best results are tabulated in Table 2 and graphically represented in Fig. 8. The following comments can be made from Table 2:

- The ESDA achieved the following results: -5.044 [dBm], -7.683 [dBm], -6.26 [dBm], -5.044 [dBm], -7.288 [dBm] and -4.507 [dBm], for scenarios 1 through 6, respectively.
- The ESDA achieved better results in 4 out of 6 scenarios, i.e., scenario 1, scenario 2, scenario 3 and scenario 5.
- The ESDA achieved the second-best result in 2 scenarios, i.e., scenario 4 and scenario 6, where the PSO achieved the best results.
- The ESDA was able to solve all scenarios while BH could not solve 2 scenarios and EM was not able to solve 3 scenarios.

The curves of convergence obtained using the proposed ESDA for the investigated scenarios are sketched in Fig. 9. The x-axis and y-axis represent the iterations and objective function, respectively. The following comments can be made from that figure:

- The ESDA has converged, i.e., most of the objective function minimization is achieved while solving all the scenarios before 300 iterations. This shows the excellent convergence ability of the ESDA, as reported in the literature.
- The objective function in almost all the scenarios is infinity at the first iterations of the optimization process. This is because the connection between sensors was not achieved initially.

The sensor transmission powers for each sensor for the investigated scenarios obtained using the ESDA are tabulated in Table 3. The following can be noticed from the table:

- The transmission power of each sensor is different from the remaining sensors.
- Depending on the scenario, the transmission is different from one scenario to another.
- The minimum sensor transmission powers for scenarios 1 through 6 are -28.329 [dBm], -28.328 [dBm], -28.329 [dBm], -28.330 [dBm], -28.328 [dBm] and -28.318 [dBm], respectively.
- The maximum sensor transmission powers for scenarios 1 through 6 are -10.262 [dBm], -15.775 [dBm], -9.192 [dBm], -14.350 [dBm], -15.776 [dBm] and -11.797 [dBm], respectively.
- The average sensor transmission powers for scenarios 1 through 6 are -21.327 [dBm], -22.547 [dBm], -23.809 [dBm], -20.502 [dBm], -22.725 [dBm] and -20.059 [dBm], respectively.

Table 2: Results comparison using different algorithms

| Algorithm | ESDA [dBm] | PSO [19] [dBm] | Simplistic Method [19] [dBm] | DE [dBm] | GA [dBm] | BH [dBm] | EM [dBm] | SSA [dBm] | SCA [dBm] |
|---|---|---|---|---|---|---|---|---|---|
| Scenario 1 | **-5.044** | -3.624 | 2.827 | -4.026 | -0.343 | Inf | Inf | -4.074 | 4.353 |
| Scenario 2 | **-7.683** | -6.669 | -2.699 | -6.758 | -1.090 | -6.798 | 7.214 | -5.841 | 7.636 |
| Scenario 3 | **-6.260** | -3.353 | 2.827 | -5.725 | -2.499 | -5.112 | 5.878 | -5.161 | 7.610 |
| Scenario 4 | **-5.044** | -5.113 | 3.842 | -4.014 | -0.529 | -4.281 | Inf | -3.389 | 8.473 |
| Scenario 5 | **-7.288** | -6.669 | -2.744 | -6.475 | -1.639 | -6.031 | 3.445 | -3.400 | 5.682 |
| Scenario 6 | **-4.507** | -5.226 | 3.865 | -3.363 | 1.766 | Inf | Inf | -0.541 | 6.532 |

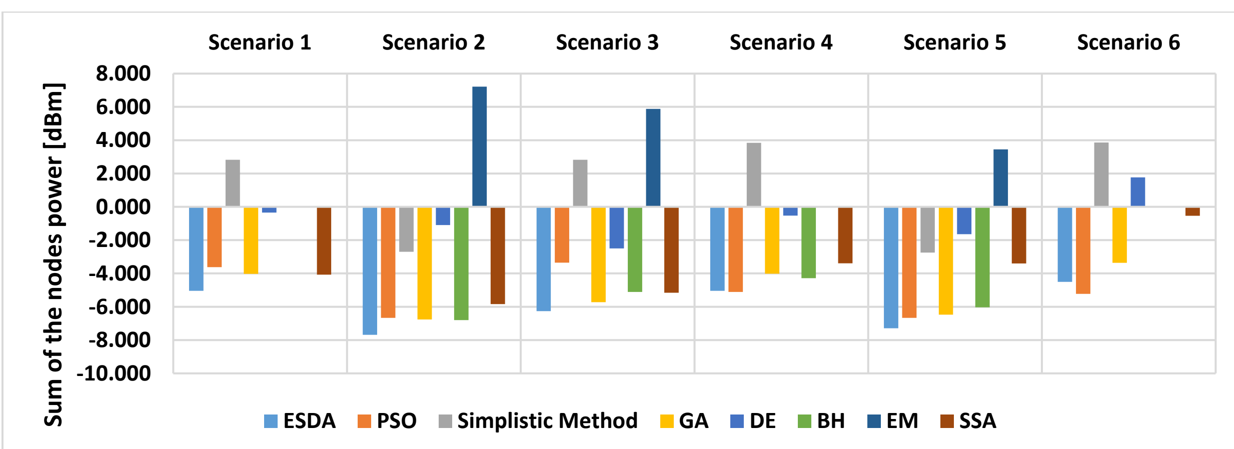


Fig. 8. Sum of all sensor nodes transmission power (fitness) for different methods.

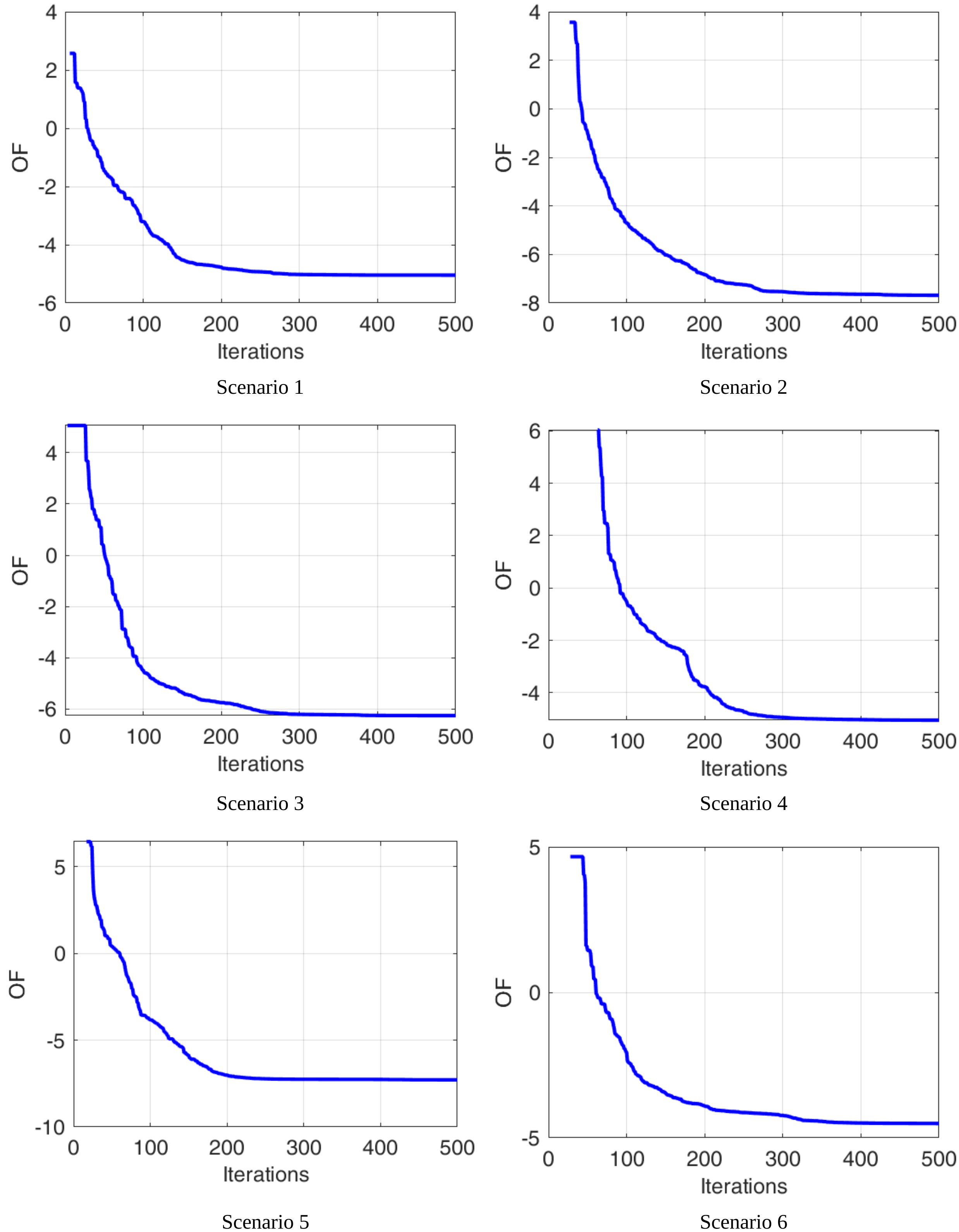


Fig. 9. Convergence curves of the ten investigated scenarios obtained using ESDA.

Table 3: The sensor transmission powers for each sensor for the six investigated scenarios obtained using the ESDA

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 3 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|
| Sensor 1 | -17.190 | -18.329 | -21.340 | -28.329 | -25.314 | -14.349 |
| Sensor2 | -21.340 | -25.318 | -28.322 | -15.318 | -28.328 | -16.025 |
| Sensor 3 | -16.288 | -21.334 | -28.326 | -28.307 | -22.232 | -25.298 |
| Sensor 4 | -28.253 | -16.288 | -28.328 | -28.317 | -18.329 | -11.797 |
| Sensor 5 | -28.327 | -19.296 | -21.326 | -15.319 | -22.308 | -11.797 |
| Sensor 6 | -12.648 | -25.302 | -22.308 | -16.025 | -17.190 | -22.296 |
| Sensor 7 | -18.330 | -25.319 | -28.329 | -16.288 | -15.776 | -25.314 |
| Sensor 8 | -16.289 | -21.339 | -14.350 | -28.326 | -28.327 | -22.307 |
| Sensor 9 | -21.333 | -16.025 | -28.329 | -16.284 | -28.324 | -28.318 |
| Sensor 10 | -21.340 | -18.784 | -25.319 | -14.350 | -28.321 | -13.278 |
| Sensor 11 | -28.315 | -22.308 | -28.320 | -17.190 | -25.313 | -21.337 |
| Sensor 12 | -28.329 | -28.325 | -28.329 | -28.328 | -25.319 | -28.297 |
| Sensor 13 | -21.340 | -28.318 | -9.192 | -28.330 | -28.326 | -19.295 |
| Sensor 14 | -21.340 | -15.775 | -28.251 | -18.328 | -15.777 | -22.307 |
| Sensor 15 | -28.328 | -25.318 | -25.315 | -22.309 | -15.777 | -22.307 |
| Sensor 16 | -10.262 | -22.306 | -21.340 | -22.307 | -18.787 | -19.295 |
| Sensor 17 | -21.340 | -28.328 | -21.340 | -18.758 | -28.325 | -19.298 |
| Sensor 18 | -28.328 | -22.308 | -28.324 | -15.319 | -18.787 | -22.303 |
| Sensor 19 | -16.289 | -28.317 | -22.309 | -16.024 | -18.328 | -18.770 |
| Sensor 20 | -21.339 | -22.308 | -17.190 | -16.288 | -25.313 | -17.190 |

## V. CONCLUSION

In this work, the ESDA has been proposed and applied to save energy in a WSN by determining different sensor powers under the constraint of all nodes must be connected. This algorithm has been compared to PSO, GA, DE, BH, EM, SSA, and SCA, found in the literature, and the results are found to be satisfactory. In 4 cases out of 6, the ESDA has obtained results than the PSO. In all cases, the ESDA has been able to converge to a solution (i.e., to find a fully connected network).

In future, different frequencies to account for other technologies like WiFi, WiMax, Zigbee, and Bluetooth can be included. Furthermore, transmission rates and power consumption can also be included in the order in order to evaluate their effects on energy-saving and network connectivity.

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**Mohammed A. Alanezi** is an Associate Professor in the Department of Computer Science in the Department of Computer Science and Engineering Technology of the University of Hafr Al-Batin University where he has been serving as Vice-rector for Academic Affairs. His research interests include eGovernment, E-Services, E-Health, IoT and Knowledge Management. He contributes also to the development of various projects and systems; much of his work has been in embracing digital transformation and improving the current technology to solve challenges facing the University of Hafr Al-Batin.

**Houssem R. E. H. Bouchekara** is a Full Professor at the Electrical Engineering Department of the University of Hafr Al Batin. He has received his B.S. in Electrical Engineering from University Mentouri Constantine, Algeria, in 2004. He has received his Master in Electronic Systems and Electrical Engineering from Polytechnic School of the University of Nantes, France, 2005. He received his Ph.D. in Electrical Engineering from Grenoble Institute of Technology, France, in 2008. His research interest includes: Optimization techniques, Magnetic refrigeration, Electromagnetics, Electric machines, and Power systems

**Muhammad Sharjeel Javaid** received his B.S. in Electronic Engineering from GIK Institute, Pakistan in 2013. Later he completed his M.S. in Electrical Engineering from King Fahd University of Petroleum and Minerals, Saudi Arabia, in 2017. He has worked as an active member of the IET GIKI Chapter, and as general secretary in the IEEE KFUPM Chapter. Currently, he is serving as Lecturer at the University of Hafr al Batin. He has a keen interest to work on Energy Markets, Distributed Generation Optimization.