Application of Harmony Search Optimization Algorithm to Improve Connectivity in Wireless Sensor Network with Non-uniform Density

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Low connectivity is a challenging problem in wireless communication sensor networks with non-uniform sensor node densities. Reliable information transmission requires the full connectivity of the network because of the multi-hop communication of wireless sensor networks. A network is fully connected if each pair of nodes can communicate with each other, either directly or through intermediate relay nodes. The current study presents a Harmony Search (HS) algorithm to improve the connectivity of the non-uniform density wireless sensor networks. HS is a meta-heuristic algorithm, which mimics the actions of harmonizing musical instruments, including memory-based, random, and pitch-adjusted play, during improvisation. In the present work, HS is used to optimize the phase shift parameters of sensors node inside the cluster to ensure maximum radiation field at the reception point. This process results in a significant increase in the coverage area of cluster nodes, consequently increasing network connectivity.

Keywords: harmony search algorithm, wireless sensor networks, connectivity, non-uniform density, cooperative transmission

1. INTRODUCTION

Advancements in microelectronics, wireless communication, and embedded microprocessors resulted in the emergence of one of the most rapidly evolving research and development fields, wireless sensor networks (WSN) [1, 2]. WSN is a complex system comprising spatially distributed autonomous devices called sensor nodes that monitor physical or environmental conditions at different locations. Sensor networks are used in various applications, such as habitat monitoring [3], target tracking, security surveillance (e.g., alert to terrorist threats [4], hazard and disaster monitoring and relief operations, health industry applications [5], and home applications (e.g., smart environment) [6].

WSN comprises one or more sinks (or base stations) and tens of thousands of sensor nodes scattered in an area. Sensor nodes collect information from the environment based on the requirements of an application or process [6]. Temperature, light, vibration,
noise, radiation, and so on, are assessed during this information gathering process [7].
The information collected by the sensor nodes “travel” through the network to the node
sinks or base stations. The sink may send queries to the nodes depending on the application
used to gather additional useful information. Every sensor should be able to communicate
with the sinks or base stations.

Sensor nodes and sinks communicate using one of the two wireless communica-
tion techniques, namely, single-hop or multi-hop (ad hoc) wireless transmission [8]. Sin-
gle-hop wireless transmissions are popular in short-range applications, such as smart
homes. However, self-organized and large-scale networks have been established because
of the low cost and low power consumption of wireless sensors. These networks have
increased flexibility in maintenance and deployment in highly dynamic environments,
such as civilian and military applications. Multi-hop wireless transmissions or the ad hoc
technique is preferred in large-scale, long-range, and highly distributed applications.
Hence, the current study focuses on WSNs that employ the multi-hop wireless transmis-
sion technique.

An ideal condition for a WSN that utilizes multi-hop communication is character-
ized by the capability of every pair of nodes to communicate with each other directly or
indirectly through intermediate relay nodes [9]. Nodes, however, may have non-uniform
density spatial distribution (i.e., all sensors are deployed in different densities in different
areas) and a limited radio range. A low density of nodes results in network partitioning,
which affects node communication. Even among high density nodes, relief features
(ponds, natural barriers, buildings, and so on) result in the isolation of certain node
groups from the network. Another reason for network disintegration is “the degradation
of energy.” This gradual failure of sensor nodes results from the depletion of reserved
energy, consequently resulting in low network connectivity.

Krohn [10] proposed a method to increase the connectivity of non-uniform density
WSNs using wave propagation cooperative transmission, which involves flooding a
message transmission through the network using a wave-front technique. Nodes that
receive a message will transmit a message several times, based on the Accumulating
Cooperative Transmission technique, resulting in significant overheads and energy usage
for the entire network. Shanoon [11] address the problem of low connectivity for non-
uniform density WSNs through Multi-Hop Cluster Transmission of Information (MHCTI)
Protocol. This protocol is based on the coherent addition of fields from closely spaced wireless nodes formed by the principle of coherent cooperative transmission of
information.

In the current paper, the connectivity of non-uniform density WSN in [11] is im-
proved using a harmony search (HS) algorithm to adjust the optimum phase shifts to
ensure maximum radiation field at the reception point. This process will result in a sig-
nificant increase in the coverage area of cluster nodes, thereby, increasing network con-
nectivity.

2. MHCTI PROTOCOL

This protocol is based on the coherent addition of fields from closely spaced wire-
less nodes using the principle of coherent cooperative transmission of information, where
the neighbouring nodes are combined in clusters [11]. A node relays information to other
nodes in the cluster to transmit information to the base station. The nodes in the cluster synchronously transmit the data to the next hop node. A summary signal and electric field intensity may increase at the reception point as a result of interference. To implement MHCTI, the network is divided into clusters or groups of nodes to enable the radiation of transmitters to synchronize the frequency and reach a stabilized phase. These clusters represent virtual antenna arrays that form the general field of radiation. Cluster formation utilizing an energy-efficient algorithm for the self-organization of nodes is based on the identification number (ID) originally assigned to each node. The total field of the radiating system nodes with complex field amplitude at a distance \( r \) from each node is calculated by the empirical formula obtained for the surface channels [11]:

\[
E = E_s \left( \frac{r}{R} \right)^d \exp(i(-kr + \phi))
\]

where \( E_s \) as the sensitivity field is the minimum field that a neighbor can detect, \( d \) is the degree of attenuation of the field and varies from \( d = 1 \) (for a model of free space) to \( d = 2 \) (for a model of propagation of radio waves over a conducting surface), \( \omega \) is the angular frequency, \( t \) refers to time, \( k \) is the wave vector in free space, and \( \phi \) is the phase.

3. HARMONY SEARCH ALGORITHM (HSA) IN WSN

HS is a metaheuristic optimisation algorithm [12] based on the imitation procedure improvisation of musical instruments. During the music improvisation procedure, each musician (= variable is a possible solution) takes (= generate) a note (= value) to determine the best sound to achieve a certain harmony (= global optimum). The primary purpose of composing a musical work or performance is to achieve harmony where individual sounds are perceived as a whole. Thus, the implementation of procedures to achieve harmony in music is similar to determining the optimum in the optimisation process, that is, the process of improvisation is similar to the procedure of finding the best solutions. On one hand, perfect harmony, as indicated in [12], is determined by the sound standards of aesthetics, where the musician is always attempting to fulfill some portion of a musical work in accordance with his understanding of ideal harmony. Alternatively, the optimal solution to a problem must be the best solution containing both the defined objectives and constraints.

These similarities between the two actions were used to develop a new algorithm. The search for harmony can be considered a successful example of the transformation of the qualitative process of improvisation (based on some random perturbations) in a quantitative optimization process according to some idealized rules [12]. The use of an algorithm to search for harmony has some advantages compared with known algorithms for optimization. A number of these advantages are presented in descending order below:

- HS algorithm does not require complex calculations;
- HS algorithm does not require the adjustment of the initial values of parameters used in the optimisation procedure, which allows for the local extremum;
• HS algorithm can work with both discrete and continuous parameters, whereas the gradient methods only work with continuous variables.

HS has been successfully implemented in various applications for optimization problems, such as energy consumption for WSNs [13], music composition [14], solving Sudoku puzzles [15], tour planning [16], web page clustering [17, 18], structural design [19, 20], water network design [21], vehicle routing [22], dam scheduling [23], ground water modeling [24, 25], soil stability analysis [26], ecological conservation [27], energy system dispatch [28], heat exchanger design [29], transportation energy modeling [30], satellite heat pipe design [31], medical physics [32], RNA structure prediction [33], and so on.

In addition, HS algorithm has been successfully implemented in WSNs applications for optimization problems. Hoang et al. [13] proposed the HS algorithm for minimizing the intra-cluster distance and optimizing the energy consumption of WSNs. The simulation results demonstrate that the proposed protocol using HS algorithm can reduce energy consumption and improve the network lifetime. Nezhad et al. [34] introduced an improved HS algorithm in a k-covered and linked WSN to realize a sensor node deployment such that the covered area is optimal and data transfer has low energy consumption. Ahmad et al. [35] put forward an HS algorithm for the broadcast scheduling problem. The HS algorithm investigates the search space efficiently and effectively by exploiting the search rules of variation and randomness of experience. Manjarres et al. [36] proposed two, namely, the objective localization approach based on the combination of the HS algorithm and a local search procedure, and exploited connectivity-based geometrical constraints to restrict the areas where sensor nodes can be located.

3.1 Problem Statement

Low connectivity is one of the most important problems in non-uniform density WSNs. Each node has a limited radio range, so the low density of nodes can result in network partitioning, consequently terminating communication between nodes, which is understood as a failure of a system network as a result of the absence of communication between nodes. The solution for this problem is to avoid network system failure.

3.2 Problem Formulation

The first step in applying an optimization method to solve an optimization problem is to model the problem in terms of an objective function.

Clusters containing \( n \) nodes in the MHCTI protocol are used when a node needs to transmit information to the base station. The information is relayed to other nodes in the cluster. The nodes in the cluster synchronously transmit and coherently combine the information to the next hop node. The combination of the total field of the radiating system for \( n \) nodes is:

\[
E_{\text{sum}} = E_s \sum_{j=1}^{n} \left( \frac{r_j}{R} \right)^{-d} \exp\left(\frac{-k r_j + \varphi_j}{R}\right),
\]  

The objective function \( E_{\text{sum}} \) is rendered in Eq. (7). The value of \( E_{\text{sum}} \) is the combination
of the total field of the radiating system for \( n \) nodes inside the cluster. The sensor nodes are assumed stationary and the communication range and physical location of all nodes in the network are known [37].

### 3.3 Study Aims

The adjusting phases \( (\phi_i) \) of (2) in [11] are not implemented in the cluster. The aims of the present study are:

1. To use an HS algorithm to adjust the optimum phase shifts of all nodes inside a cluster to ensure maximum radiation field at the reception point to improve network connectivity.
2. To study the effect of HS on the dependence of network connectivity on the total number of nodes.

### 3.4 Optimization Model

In the previous section, the model of \( E_{\text{sum}} \) was formulated to maximize the total field of the combined radiating system for \( n \) nodes inside a cluster:

\[
Max. E_{\text{sum}}(\phi) = E \sum_{j=1}^{n} \left( \frac{S_j}{R} \right)^d \exp \left[ i(-k r_j + \phi_j) \right],
\]

Subject to:
\[
-\pi \leq \phi_i \leq \pi, \quad 1 \leq d \leq 2,
\]

\[
r = \sqrt{[x_B - x_A]^2 + [y_B - y_A]^2}
\]

where \((x_B, y_B)\) and \((x_A, y_A)\) are the coordinates of sensors B and A, respectively.

This objective function tends to maximize the combination of the total field of the radiating system and optimize the phase shift of the cluster to ensure maximum radiation field at the reception point. To optimize the selection of phase shift, HS is run to determine the optimal phase shift. The objective function (3) is used to compute the optimum.

### 3.5 HS Algorithm for the Combined of the Total Field of the Radiating System Model

In the present work, the HS algorithm for the total field of the sum for radiating system for \( n \) nodes inside a cluster \( E_{\text{sum}} \) model is presented. This HS algorithm is used to control the zone covers of the sending cluster by adjusting the optimum phase shifts \( \phi_i \) of nodes to ensure maximum radiation the field \( E_{\text{sum}} \) at the reception point. HS comprises five steps. Fig. 1 shows the flowchart of HS to \( E_{\text{sum}} \), which will be discussed in the following steps.

**Step 1:** The HS and optimization problem parameters are initialized.

In the first step, the optimization problem is specified as follows:
Maximize \( E_{\text{sum}}(\phi) \)
Subject to \( \phi_i \in X_i, \quad i = 1, 2, \ldots, N \),
where $E_{\text{sum}}(\phi)$ is an objective function; $N$ is the number of decision variables; $\phi$ is a solution vector composed of each decision variable $\phi_i$; $X_i$ is the set of possible range of values for each decision variable, that is, $L\phi_i \leq X_i \leq U\phi_i$, where $L\phi_i = -\pi$ and $U\phi_i = \pi$ is the lower and upper limit for each decision variable, respectively.

For the present problem, the combination of the total field of the radiating system $E_{\text{sum}}$ was maximized and the phase shift of the cluster was optimized. This method is defined by the objective function given in Eq. (3). The solution to the formulated problem is the adjustment of the phases ($\phi$) of the $n$ nodes for the cluster in the network.

The number of solution vectors (sets of decision variables) in the Harmony Memory Matrix is the Harmony Memory Size (HMS). For the formulated problem, HMS is set at 50. To use this memory effectively, the HS adopts a parameter called Harmony Memory Considering Rate (HMCR). If this rate is set extremely low, only a few elite harmonies will be selected and may converge slowly. If this rate is extremely high (near 1), the pitches stored in the harmony memory are mostly used, and newer pitches are not explored well. Therefore, HMCR is assumed as 0.95. The second component is the pitch adjustment, which is governed by the Pitch Adjusting Rate (PAR) assumed as 0.8.
maximum number of searches (stopping criterion) is given as 1000. The HMCR, PAR, and the stopping criterion initialized are used to improve the solution vector.

The parameters of objective function $E_{sum}(\phi)$ are considered as follows:

- Fixed threshold sensitivity $E_s = -85$ dB,
- Degree of attenuation of the field $1 \leq d \leq 2$,
- Transmission Range of node $R = 6.25$ m,
- Wavelength $\lambda = 0.125$ m,
- Wave vector in free space $k = \frac{2\pi}{\lambda}$,
- Distance between nodes and clusterhead, $r = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2}$ where $(x_B, y_B)$ and $(x_A, y_A)$ are the coordinates of sensors B and A, respectively.
- Phase shift $-\pi \leq \phi \leq \pi$.

**Step 2:** The Harmony Memory (HM) is initialized

The initial HM comprises an HMS number of randomly generated solution vectors for the optimization problem under consideration. The formulated problem can be solved by evaluating the harmonic values of the phase shift for $n$ nodes inside the cluster. HM with the size of HMS can be represented by Eq. (5):

$$HM = \begin{bmatrix} \phi_1^1 & \phi_1^2 & \cdots & \phi_1^n & E_{sum}(\phi^1) \\ \phi_2^1 & \phi_2^2 & \cdots & \phi_2^n & E_{sum}(\phi^2) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \phi_{HMS}^1 & \phi_{HMS}^2 & \cdots & \phi_{HMS}^n & E_{sum}(\phi_{HMS}) \end{bmatrix}$$

Each row of the HM is a random solution for the optimization problem. The value of the objective function given by Eq. (3) is computed for each harmony vector and represented by $E_{sum}(\phi^j)$.

**Step 3:** A new harmony from the HM is improvised

The improvisation of the HM is performed by generating a new harmony vector, $\phi^j = (\phi^1_j, \phi^2_j, \ldots, \phi^k_j)$, where $j = 1, 2, \ldots, k$. Each component of the new harmony vector $\phi^j$ is generated using Eq. (6) based on the HMCR defined in step 1:

$$\phi^j \leftarrow \begin{cases} \phi^j \in \text{HM with probability } HMCR \\ \phi^j \in \phi, \text{ with probability } (1 - HMCR) \end{cases}$$

HMCR is defined as the probability of selecting a component from the HM members. Therefore, $(1-\text{HMCR})$ is the probability of generating HM randomly. If $\phi^j$ is generated from the HM, then this value is further modified or mutated according to the PAR. PAR determines the probability of a candidate from the HM to be mutated, and $(1-\text{PAR})$ is the probability of doing nothing. The pitch adjustment for the selected $\phi^j$ is given by Eq. (7):

$$\phi^j \leftarrow \begin{cases} \phi^j + f \cdot \mu(-1,1) \text{ with probability } PAR \\ \phi^j \text{ with probability } (1 - PAR) \end{cases}$$
where $f_w$ is the pitch bandwidth or the amount of maximum change in pitch adjustment, which may range from $(0.01 \times \text{allowed range})$ to $(0.001 \times \text{allowed range})$. The equation $u(-1, 1)$ is a uniformly distributed random number between $-1$ and 1.

**Step 4:** The HM is updated

The newly generated harmony vector, $\phi_i' = (\phi_1', \phi_2', \ldots, \phi_k')$ is evaluated in terms of the objective function value. If the objective function value for the new harmony vector is better than that for the worst harmony in the HM, then the new harmony is included in the HM, and the existing worst harmony is excluded from the HM.

**Step 5:** Step 3 is repeated until the termination criterion is reached

The current best solution is selected from the HM after the termination criterion (number of searches) is satisfied. This process is the solution to the formulated optimization problem.

4. SIMULATION RESULT AND DISCUSSION

The evaluation of the HS algorithm is conducted by simulating a 1600 node network with MATLAB. Sensor nodes are deployed in an area of $1200\lambda \times 1200\lambda$. Each node has a radius of $30\lambda$. Nodes are distributed in non-uniform density. The coordinates of the nodes in each density are selected randomly with a uniform distribution function on the grid with the step $\lambda/2$.

In a numerical network simulation assumed with bi-directional communication, the relationship between two clusters is possible, provided that at least one of the nodes in the cluster C is within the coverage area of the cluster D, and at least one cluster node D is within the coverage area of the cluster C. The whole network was divided into clusters, and information exchange occurred between these clusters [11].

The HS algorithm was applied to find the best phase shift of each node within a cluster that can maximize the objective function $E_{\text{sum}}(\phi)$. The parameters of the HS algorithm, such as HMS, HMCR, and PAR, were selected as 50, 0.95, and 0.8, respectively. The HS algorithm is heuristic in nature, so 50 trials were performed to obtain the best solution. Table 1 shows distance and average value from $n$ nodes to the clusterhead for all 13 convergence cases, where distance $r$ is evaluated using Eq. (4).

Fig. 2 plots the phase shift value for the two cases (i.e., $n = 2$ and $n = 14$) and set to examine the convergence rate of the phase shift value when the three operators: memory consideration HMS, random consideration HMCR, and pitch adjustment procedures PAR are set to work for generating the new harmony solution. This means the HSA is able to find the best solutions (i.e., phase shift) with few numbers of iterations (i.e., number of searches) as shown in Fig. 2.

Fig. 3 plots the total field value of the combined radiating system for the clusters (when $n = 2$ to 14) of all 13 convergence cases. Cases 1-4 show the convergence behaviour of HS when the number inside cluster is defined as $n = 2$, $n = 3$, $n = 4$, and $n = 5$. Convergence was extremely fast in these cases, and the value of the fitness function are close to one another, especially when $n = 4$ and $n = 5$. Moreover, the value of the objective function $E_{\text{sum}}$ when $n = 6$ is greater than when $n = 7$. This finding is caused by the
Table 1. The distance between nodes and clusterhead inside cluster for all cases.

<table>
<thead>
<tr>
<th>Distance</th>
<th>( n = 2 )</th>
<th>( n = 3 )</th>
<th>( n = 4 )</th>
<th>( n = 5 )</th>
<th>( n = 6 )</th>
<th>( n = 7 )</th>
<th>( n = 8 )</th>
<th>( n = 9 )</th>
<th>( n = 10 )</th>
<th>( n = 11 )</th>
<th>( n = 12 )</th>
<th>( n = 13 )</th>
<th>( n = 14 )</th>
</tr>
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<tbody>
<tr>
<td>( r_5 )</td>
<td></td>
<td></td>
<td>3.9512</td>
<td>4.1203</td>
<td>3.9383</td>
<td>5.1384</td>
<td>4.1902</td>
<td>4.0699</td>
<td>4.1260</td>
<td>4.9307</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r_6 )</td>
<td>4.2501</td>
<td>4.7312</td>
<td>4.0730</td>
<td>4.3866</td>
<td>5.1939</td>
<td>5.8035</td>
<td>5.9071</td>
<td>4.6900</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( r_7 )</td>
<td>4.2122</td>
<td>4.1996</td>
<td>5.4887</td>
<td>3.9559</td>
<td>5.4760</td>
<td>5.1254</td>
<td>4.8438</td>
<td>5.5492</td>
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<tr>
<td>( r_8 )</td>
<td>3.8678</td>
<td>4.6809</td>
<td>4.5754</td>
<td>4.0922</td>
<td>4.2367</td>
<td>4.4130</td>
<td>4.5182</td>
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<td>( r_9 )</td>
<td>3.8815</td>
<td>3.7500</td>
<td>4.8389</td>
<td>4.1606</td>
<td>3.8374</td>
<td>4.1443</td>
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<td>( r_{10} )</td>
<td>3.9309</td>
<td>3.9520</td>
<td>4.2259</td>
<td>4.7518</td>
<td>4.8541</td>
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<td>( r_{11} )</td>
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<td>3.8284</td>
<td>3.9665</td>
<td>3.8070</td>
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<td>( r_{12} )</td>
<td>5.7903</td>
<td>4.9503</td>
<td>6.0650</td>
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<td>( r_{13} )</td>
<td>5.3954</td>
<td>5.2882</td>
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<td>( r_{14} )</td>
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<td>6.2219</td>
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Fig. 2. Results of HS phase shift convergence (\( n = 2 \) and \( n = 14 \)).

Fig. 3. The total field value of the combine radiating system for clusters for 13 convergence cases.
distance between the nodes and the clusterhead inside the cluster and the density of nodes inside the cluster. According to Eq. (1), the field strength $E$ is proportional to $\frac{1}{r}$ when $d = 1$ and proportional to $\frac{1}{r^2}$ when $d = 2$. Therefore, the value of the objective function increases when the average distance between the nodes and the clusterhead decreases. This phenomenon occurs, for example, when $(n = 6$ and $n = 7)$. The average distance between the nodes and the clusterhead when $n = 6$ (Table 1) is and that when $n = 7$ is 5.2435m. The value of the objective function $E_{\text{sum}}$ when $n = 6$ is significantly greater than when $n = 7$.

Fig. 4 Plots the dependence of network connectivity on the total number of nodes with and without the use of the HS algorithm. Results of the MHCTI using the HS algorithm is compared with those of previous approaches, such as the hybrid multi-hop cooperative transmission method [10], in terms of connectivity. Network connectivity during the numerical experiments was calculated using the following equation [11]:

$$
\varepsilon = \frac{N_c}{N},
$$

(8)

where $N_c$ is the number of nodes available for the base station, and $N$ is the total number of nodes.

The number of nodes changed from 200 to 1600 in steps of 10 when network connectivity was calculated. Fig. 4 shows the results of the network connectivity calculations and a comparison between the application of the MHCTI using the HS algorithm with parameters $d = 1$ (free space model) and $d = 2$ (over conducting surface model), the application of MHCTI without HS algorithm and with hybrid multi-hop cooperative transmission method [10] for free space model. As shown earlier, the degree of attenuation of the field significantly affects the efficiency of the coherent addition of capacity. Thus, the use of MHCTI with HS increases network connectivity, especially when $d = 1$. However, to guarantee that all nodes can communicate with each other, the number of nodes should exceed 1000 for $d = 1$ and greater than 1200 for $d = 2$. To guarantee node communication in cases of MHCTI where HS is not applied, the number of nodes should exceed 1100 for $d = 1$ and greater than 1400 for $d = 2$.

Based on Fig. 4, the hybrid multi-hop cooperative transmission protocol is worse than the MHCTI for $d = 1$. The hybrid multi-hop cooperative transmission approach requires approximately 1350 nodes to guarantee communication among all nodes. When approximately 700 nodes are present using the MHCTI for $d = 1$, 86% connectivity is possible, and 20% connectivity is possible with the hybrid multi-hop cooperative transmission protocol. These connectivity values cannot be improved by any routing or other broadcast technique.

Thus, the use of MHCTI with HS for $d = 1$ increases network connectivity by 12.72% and by 14.28% with parameter $d = 2$. Based on Fig. 4, the connectivity of MHCTI with HS when $d = 1$ and $d = 2$ is better than that of an MHCTI method with parameters $d = 1$ and $d = 2$. When approximately 900 nodes are present using the MHCTI method with $d = 2$, 47% connectivity is possible, and 81% connectivity is possible with MHCTI with HS for $d = 2$. When 600 nodes are present using MHCTI with HS for $d = 1$, 89% connectivity is possible, and 57% connectivity is possible with the MHCTI method with $d = 1$.

Based on Fig. 4, the connectivity in MHCTI with HS when $d = 1$ is better than that
in a hybrid multi-hop cooperative transmission protocol. When 600 nodes are present using MHCTI with HS when $d = 1$, 89% connectivity is possible, and 12% connectivity is possible with the hybrid multi-hop cooperative transmission protocol. This connectivity value cannot be improved by any routing or other broadcast technique.

Given that the radius of the single node $R$ is fixed and does not depend on $d$, the connectivity of the network with a regular method does not depend on parameter $d$. Thus, the relationship between the clusters must be bi-directional. When a cluster message is sent, the clusterhead node waits for confirmation from other clusters. Information confirming correct reception can be taken directly to the clusterhead node or to any other node in the cluster. Data transfer is thus initiated by the clusterhead node. If, after some period, the clusterhead node failed to receive confirmation, restructuring phases are implemented in the cluster, and data are re-transmitted across the cluster. The restructuring phase of radiation with the use of HS occurs in each cluster node. The zone that covers the sending cluster can be controlled by the harmonic phase of radiation in wireless nodes. The implementation of HS enhances the probability of hitting the receiving node in the coverage area of the cluster, which mitigates the harmful effect of broken coverage.

![Graph showing the dependence of network connectivity to the total number of nodes for MHCTI, MHCTI with HS and the hybrid multi-hop cooperative transmission protocol.](image)

Fig. 7. The dependence of network connectivity to the total number of nodes for MHCTI, MHCTI with HS and the hybrid multi-hop cooperative transmission protocol.

5. CONCLUSION

The present study proposed the HS algorithm for improving the connectivity of WSNs with non-uniform density. The five primary steps of HS have been thoroughly described. The HS is evaluated using 13 convergence cases, each with a different number of nodes inside the cluster. Network connectivity with and without the use HS was calculated. The HS algorithm was used to improve both the network connectivity and the harmonic phases in the tuning of the emitter. The actual condition of multi-path propagation nodes reached the zone-fading signal, resulting in broken node communication. The radiation field of the cluster was controlled by adjusting the phases in the transmitter to effectively deal with similar interference effects.
REFERENCES


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