Maximizing Lifetime of Wireless Sensor Networks Based on Whale Optimization Algorithm

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Abstract. The lifetime of wireless sensor networks (WSNs) are considered one of the most challenges that face the topology control of WSNs. Topology control of WSNs is a technique to optimize the connections between nodes to reduce the interference between them, save energy and extend network lifetime. In this paper proposed an algorithm based on Whale Optimization Algorithm (WOA) called WOTC, the paper provides a discrete version of the WOA, where the position of each Whale is calculate and represented in a binary format. The proposed fitness function is designed to consider two main target; a minimization in numbers of active nodes, and low energy consumption within these nodes to overcome challenges that face topology control to prolong the WSNs lifetime, the simulations were carried out using Attaraya a simulator. Consequently, the results showed that the final topology obtained by WOTC is better than A3 topology depending on the number of neighbors and their energies for active nodes, use a graph traversal function to ensure that all nodes which selected in network are covered in the best topology selection.

Keywords: Topology control protocol · Whale optimization algorithm · Swarm intelligence · Wireless sensor networks

1 Introduction

Wireless Sensor Networks (WSNs) is considered very popular given a large number of application domains where they can provide useful information about. Nevertheless, WSNs is considered to be very limited in terms of computational, communication, storage, and energy resources and capabilities. These constraints are well-known that energy conservation is the most important aspect and the most expensive function in terms of energy consumption is communications [1].

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WSNs are special form of the wireless networks with their dynamic topology that connect their members (sensors). This dynamic feature is intended through the density deployments of these sensor nodes as a recovery plan for the potential failure of some of them. Usually failures are related to the constrained resources attached with those sensors [2].

Topology Control (TC) consist of two separate components: the topology construction mechanism, which produces a reduced topology, and the topology maintenance mechanism, which changes the reduced topology, and together will increase the network lifetime compared with a continuously run WSN without topology control. The A3 algorithm is evaluated using simulations and compared with the Energy Efficient CDS (EECDS) [3] and the CDS-Rule-K [4] algorithms. TC is recognized to save energy and extend the lifetime of wireless sensor networks and considered one of the most fundamental problems in WSNs [5], many of applications can use topology control WSNs including national security, surveillance, health care, earthquake stations. Sensor nodes contain small devices such as sensors, transceivers, processing, storage and actuators [6].

There are many of algorithms for topology control. Some of them based on the Graph Theory such as the work of Li et al. [7] where they proposed a minimum spanning tree-based algorithm denoted as LMST. R.C. Eberhart and J. Kennedy proposed technique to maximize lifetime network based on scheduling method [8] based automata. Other topology control algorithms applied a number of bio-inspired techniques to build that topology such as the PSO-minimum spanning tree-based topology control scheme [9], which entitled the non-dominated discrete particle swarm optimization (NDPSO). Fouad et al. [10] proposed approach using PSO to select position of sink node with reduce the number of active nodes to prolong network's lifetime. Matheswaran and Muthusamy proposed a hybrid algorithm of both Bee Algorithm and Simulated Annealing for a weighted minimal spanning tree(BASA-WMST) [11].

The structure of the paper is organized as follows: We first introduce In Sect. 2, overview the whale optimization algorithm and topology control techniques, in Sect. 3 the proposed Whale optimization based topology control algorithm, In Sect. 4, simulation results are considered, and we conclude the paper in Sect. 5.

2 Preliminaries

2.1 Whale Optimization Algorithm

Whale Optimization Algorithm (WOA) proposed by Mirjalili et al. [12], is considered one of swam intelligent application [13] that is a novel nature-inspired meta-heuristic optimization algorithm, humpback whales swim around prey within a shrinking circle and along a spiral-shaped path simultaneously to create distinctive bubbles along a circle or '9'-shaped path. To simulate this behavior in WOA, their formulations are designed as follows:

Shrinking encircling preys: The target prey and the other search agents try to update their positions towards it. This behavior is represented by the following formula:

$$\overrightarrow{X}(t+1) = \overrightarrow{X}(t) - A.\overrightarrow{D} \quad (1) \qquad \overrightarrow{D} = |C\overrightarrow{X}^*(t) - \overrightarrow{X}(t)| \quad (2)$$

$$A = 2.a.r - a \quad (3) \qquad C = 2.r \quad (4)$$

Where $\overrightarrow{X}$ is the historically best position, $\overrightarrow{X}$ is a whale position and t indicates the current iteration. A is linearly decreased from 2 to 0 and r is a random number in the range of [0,1]. The sign || denotes the absolute value.

Spiral bubble-net feeding maneuver: A spiral equation is used between the position of whale and prey as follows:

$$\overrightarrow{X}(t+1) = e^{bk}.cos(2\pi k).D' - \overrightarrow{X}^*(t) \quad (5) \qquad D' = |\overrightarrow{X^*}(t) - \overrightarrow{X}(t)| \quad (6)$$

Where b is a constant, and k is a random number in the range of $[-1, 1]$.

Search for prey: The search agent is updated according to a randomly chosen search agent instead of the best search agent:

$$\overrightarrow{D^{"}} = |C.\overrightarrow{X(t)}_{rand} - \overrightarrow{X}(t)| \quad (7)$$

$$\overrightarrow{X}(t+1) = \overrightarrow{X(t)}_{rand} - A.\overrightarrow{D^{"}}| \quad (8)$$

where $\overrightarrow{X(t)}_{rand}$ is selected randomly from whales in the current iteration. Finally, follows these conditions:

- $|A| > 1$ enforces exploration to WOA algorithm to find out global optimum avoids local optima.
- $|A| < 1$ For updating the position of best current search agent selected.

2.2 Topology Control Techniques

WSNs that impact on its operational lifetime, a number of algorithms were designed for conserving the nodes energy. The topology control protocols are of these algorithms that attempt to reduce the energy consumption within WSNs. A topology control protocol is a process of controlling the number of active links between nodes, or selecting a minimum subset of nodes to join the working backbone [14]. The main challenge for these protocols is how to achieve this energy conservation without sacrificing the important networks characteristics such as connectivity and sensing coverage [15]. The A3 [16] that used to construct a Connected Dominating Set (CDS) of active nodes out of a fully connected graph. Both algorithms are based on a weighted distance-energy-based metric. This metric is calculated based on the Received Signal Strength Indicator (RSSI) of an initial discovery message, along with the residual energy of the receiver node to guarantee connectivity among all nodes within the network. This backbone takes the sensing lead while the rest of nodes turn themselves off (a sleep mode) in order to save their energy for future maintenance procedures.

3 The Proposed WOTC Algorithm

This section describes the design and the implementation issues of whale optimization algorithm for topology control (WOTC) as shown in Fig. 1.

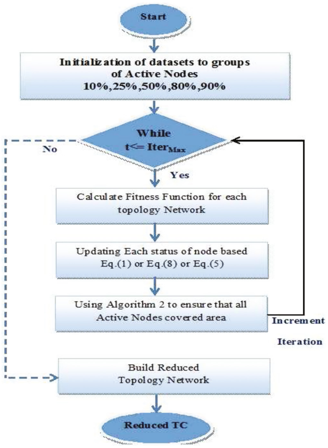


Fig. 1. The flowchart of WOA optimized TC (WOTC).

The whales position in WOA $\overrightarrow{X} = x[1], x[2], ., x[n]$ which represent candidates solutions. The candidate solution $\overrightarrow{X}$ is converted into a binary vector using a sigmoid function, this workaround has been used for similar problems [17]. Each whales position $\overrightarrow{X}$; x[i] takes either the values 1 or 0 which means the node i within the final topology is active or inactive, respectively. Equation 9 is used to convert $\overrightarrow{X}$ into Bi (the binary vector) through the application of a sigmoid. This approach only updated whale position vector is forced to be binary; see Algorithm 1 using the main updating equation as shown in Eq. 9.

$$B[i] = \begin{cases} 0 & \text{if } sigmoid(X[i]) < rand \\ 1 & otherwise \end{cases} \tag{9}$$

where rand is a random number drawn from uniform distribution ∈ [0,1], and sigmoid(a) is defined in Eq. 10.

$$Sigmoid(a) = \frac{1}{1 + e^{-10(a-0.5)}} \tag{10}$$

$$f(x) = \sum_{i=1}^{n} \frac{B[i]}{N_i.E_i} \tag{11}$$

Where N_i the set of neighbors of a node i, E_i is the initial energy in node i. One drawback of Eq. 11 is the fairness between nodes; since the nodes with low energy with a high number of nodes that covered from it.

The fitness function alone does not ensure that the final topology will cover all nodes. So The breadth-first search is used to check if all nodes are covered

Algorithm 1. Pseudo code of WOTC algorithm.

```
Input: A graph represents the nodes and their neighbors in the input WSN
Output: The final reduced topology
Randomly Initialize the whales population X[i](i = 1, 2, ..., n).
Initialize the number of maximum iteration T convergence windows check.
while t <= T do
    ForEach candidate network solution Xi do
     Convert network topology into a binary By Eq. 9
     Calculate the fitness for each network By Eq. 11
    End ForEach
    X = the best network topology.
    Calculate and Update a; A, C, p and l.
    ForEach Network Topology X[i] do
    if p < 0.5 then
        if (|A| < 1) then
            Update status of the current node by Eq. 1
        else(|A| ≥ 1)
            Select a random search agent (X_rand)
            Update status of the current node by Eq. 8
        end if
    else(p ≥ 0.5)
        Update status of the current node by Eq. 5
    end if
    End ForEach
end while
```

by neighbors of active nodes in the topology. Description of the function used to calculate the fitness value is outline in Algorithm 2.

4 Experimental Results

The proposed WOTC was implemented and evaluated using a Java-based simulation tool called Atarraya [18]. Table 1 illustrates a summary of the most important simulation parameters that were adjusted for the experimental scenarios.

The simulations of nodes are assumed to mimic the characteristics of simple sensors with the energy model that defined in [19]. The performance analysis calculated the mean of average of NRuns = 10 different runs of the algorithm that is calculated for both algorithms A3 and the WO-TC, Tables 2 and 3 summarizes all obtained results, where N, T, AN, Energy and Ratio means the network size, total network energy, number of active nodes, Energy consumption and Ratio of active nodes to the rest nodes respectively.

Topology results of the A3 and WOTC algorithms are shown in Fig. 2 for network size 200, red color represents active nodes and blue color represents inactive nodes. The main target of constructing a reduced topology has been achieved where the number of active nodes (AN) decreased using the proposed algorithm WOTC compared to the A3 algorithm. Figure 3a shows the number

Algorithm 2. Calculating fitness value per each population solution.

```
Input: Bi binary vector that representing a topology. N number of nodes within
    the network. SN refer to the sink node
Output: The fitness value of the input solution
Create hashset of all active nodes within the B vector.
Create empty hashset Coverlist, to contain all covered nodes
Create empty queue Q.
Enqueue SN in Q
intialize Fitness = 0.
while Q is not empty do
    Dequeue node s from Q.
    Fitness+ = 1/Es
    mark s as Visited
    intilaize number of neighbors Ns = 0.
       ForEach node v adjacent to s do
         Ns+ = 1
         Fitness = Fitness.1/Ns
          If v is not in the Coverlist then
             add v to Coverlist.
          EndIf
          If v is active and is not visited then
            Enqueue v in Q.
          EndIf
       End ForEach
end while
If number of nodes in C≠ n then
Fitness = ∞
EndIf
```

of active nodes for WOTC and A3. Figure 3b illustrates energy consumption for active nodes in a network and Fig. 3c illustrates the ratio between AN obtained by both algorithms to the remaining number of nodes.

However, a brief comparison with the previous related studies is presented in Table 4. The information about the number of nodes (N), distribution methods, techniques (used reduce the number of active nodes and maximize the lifetime) reported in previous studies are presented in Table 4. Consequently, it is seen that the proposed WOTC algorithm providing the best performance in comparison to the recent approaches.

4.1 Complexity Analysis

The expected runtime of first part is No of nodes O(n), The run time of second part are $O(n_{AV} * d)$ where n_{AV} is No of active nodes and d is average node degree. The worst case a solution has all its nodes active; i.e.n_{AV} = n. Figure 4 summarizes the average number of iterations required for convergence and its standard deviation.

Table 1. Atarraya simulation parameter.

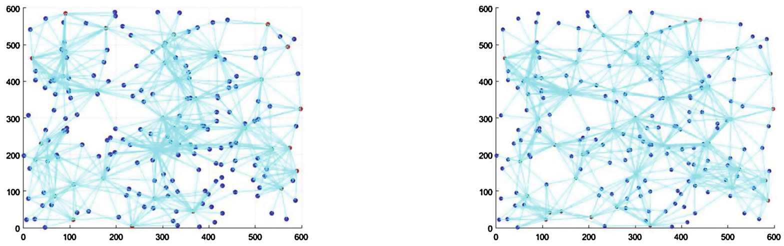
Parameter	Value
Deployment area	600 m * 600 m
Number of nodes	100, 200, ...,1000
Sensor node model	Simple
Node communication	range 100 m
Node sensing	range 20 m
Node location distribution	Uniform
Node energy distribution	Uniform
Max energy	1000 milliamperes-hour(mA-h)

Table 2. Results obtained from the A3 algorithm.

N	T	AN	Energy	Ratio
100	48852	30	12500	0.3
200	94623	44	22799	0.22
300	153785	40	19131	0.13
400	198407	44	23214	0.11
500	244942	46	25188	0.092
600	306955	42	19437	0.07
700	354704	40	20514	0.057
800	388703	41	18401	0.051
900	455076	49	29720	0.054
1000	500135	46	25833	0.046

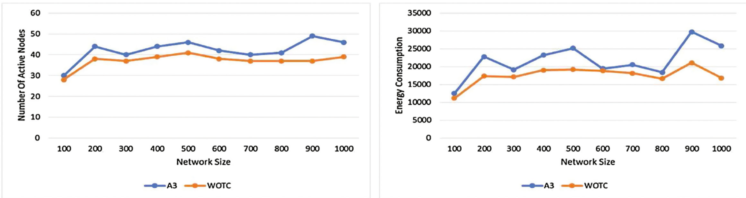
Table 3. Results obtained from the WOTC algorithm.

N	T	AN	Energy	Ratio
100	48852	28	11153	0.28
200	94623	38	17391	0.19
300	153785	37	17118	0.12
400	198407	39	19007	0.098
500	244942	41	19197	0.082
600	306955	38	18851	0.063
700	354704	37	18173	0.053
800	388703	37	16661	0.046
900	455076	37	21082	0.041
1000	500135	39	16829	0.039

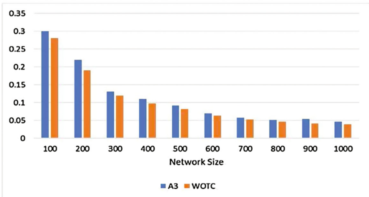


(a) A3 algorithm. **(b)** WOTC algorithm.

Fig. 2. Topology results of the A3 and WOTC for 200 nodes.



(a) No of active nodes. **(b)** Energy consumption.



(c) Ratio of active nodes to the rest nodes.

Fig. 3. Topology results of the A3 and WOTC.

Table 4. Comparison WOTC algorithm with other studies.

Ref	Techniques	N	Distribution
[20]	Active nodes scheduling	110	**AGN Randomly**
[21]	SACR protocol	100: 500	**Randomly Distributed**
[22]	Scheduled activity EADC	100	**Randomly**
[23]	Energy Balanced Topology Control	200	**200 nodes are placed in random locations**
[24]	PSO	100	**Uniform distribution**
Proposed	WOTC	100: 1000	**Dividing nodes to 5 groups**

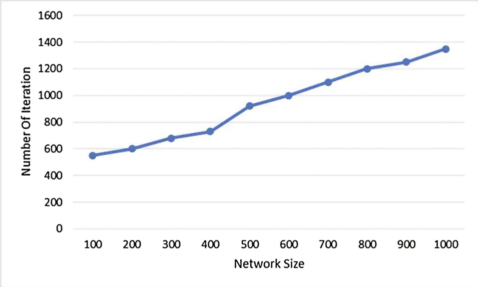


Fig. 4. Average number of iterations required for convergence

5 Conclusion

This paper introduces a topology control protocol based on Whale Optimization intelligent approach for wireless sensor nodes. The paper provides a discrete binary version of the original Whale algorithm in which the position of each Whale is calculated and represented in binary format. Moreover, the algorithm introduces a function that minimizes the number of active nodes with low energy consumption within the selected nodes without losing the network coverage and connectivity characteristics. Also, the paper introduces a performance analysis between the proposed algorithm and the A3 topology construction algorithm. The experimental results showed the advantages of the proposed algorithm in terms of a significant reduction in the number of active nodes within the constructed topology compared to the A3 algorithm. Moreover, the iterations required to converge to a suitable solution are within acceptable ranges.

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