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Linkage and Connectivity Control in Wireless Sensor Network: A New Mechanism

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ABSTRACT

Recent developments in electronics and wireless communication play a leading role in manufacturing sensors with reduced power consumption that have wireless connectivity and limited processing capabilities. Due to the limitation of battery in sensor nodes, one of the main challenges in this type of network is energy consumption, which is directly related to the lifetime of the network. Another important issue is to keep nodes connected in the network during data transmission. For these purposes, a connectivity control system is required. By improving the tree growth algorithm in the network graph, an optimal graph using a suitable path for data transmission in the network is designed. Connectivity control significantly improved system performance in terms of network power consumption and lifetime. In this paper, a new algorithm for connectivity and linkage control, based on sequential mode is presented, which has achieved a significant improvement compared to an ordinary algorithm. The outcomes of the proposed algorithm on the selected model show 56% improvement in the remaining battery charge. In addition, the end-to-end delay was reduced by 0.5 m seconds in the network.

Keywords— Wireless Sensor Network , Connectivity Control, Power Consumption, Path Loss.

1. Introduction

Recent advances in electronics and wireless communications have enabled the design and construction of sensors with low power consumption, resource allocation, small size, reasonable price, and a variety of applications. These small sensors, which are capable of performing functions such as perceiving various environmental information, and processing and exchanging information, have given rise to the idea of creating and expanding a network called a Wireless Sensor Network (WSN). In recent years, WSN has been widely used, such as battlefield, vehicle networks [1, 2, 3] and IoT, partner robot networks [4]. The WSN is made up of widely distributed, independent sensors that collectively measure physical quantities or environmental conditions such as temperature, sound, vibration, pressure, motion, or pollutants. Usually, each sensor node consists of components such as a power supply, memory, controller, communication device, and sensor device. Perception of various environmental information, processing, and exchange of information require energy consumption. Meanwhile, a significant amount of energy is spent on communication in the network [5, 6]. Since increasing the lifespan of such networks is directly related to reducing energy consumption, the main challenge is to optimize energy consumption throughout the network. Many researchers have studied the issue of energy efficiency in many types of WSNs [7, 8]. One of the approaches considered by researchers in recent years to reduce energy consumption in WSNs is the use of connectivity control [1, 3, 7, 9]. In practice, interconnection control reduces the complexity of network interconnections and reduces the energy consumed in network communication, which increases the life of the network. Correlation control can be flat and hierarchical. In the flat method, all nodes have the same role and the connection control method is done through power control. In the hierarchical method, nodes have different roles and connection control is done by controlling connections or nodes. Connectivity control in its hierarchical networks is done in two ways: backbone and clustering [11-13]. The motivation of the research in the literature focused on the deployment problem of WSNs in general. Our contribution to this research is to figure out the better connective route in the network. In accordance with these field of research, our objective focus on the design of a network graph path in order to reach the qualified route. In this research, also, the low-cost path, linkage, and connectivity are important to reach the goal. Besides that, the least selection of nodes is mentioned to keep the energy of each node. Though designing WSN many challenges can appear in the form of deployment, localization, communication, data gathering, coverage, and tracking, the most important issue that we focus on here in this research is the energy consumption and connectivity problem, which is the first major challenge in designing a WSN application. Additionally, in our simulation the end-to-end delay and the number of selected node in neighbor area, which is intervened to algorithm calculation has been investigated.

2. Related works

With a simple search about connectivity and network topology, we may find many good research in this area, in different networks. Topology design and optimization in network performance is an interesting topic for researchers.

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Here we mentioned some related research about that, however, we can find more different aspect of view in this area. He et al. presented a multi-objective genetic algorithm for optimization of the lifetime and energy consumption of network, and its performance [13]. In another study, Berre et al. investigated the non-dominated sorting genetic algorithm-II, a multi-objective practical swarm optimization is used to improve coverage and minimize sensor node number [14]. Khalesian et al. simulated the Pareto-based multi-objective evolutionary approach to maximize coverage and minimize energy consumption [15]. Moh'd Alia et al. considered the coverage with minimum cost in [16] using Harmony Search Algorithm. Prolonging the network lifetime was considered in [17] for the target coverage problem by Yarinezhad et al. Anomalous Cluster Heads and Nodes in WSNs are also investigated by Gorgbandi et al. [18]. Surendran et al. studied a distributed algorithm to find nodes to connect dominant nodes [19]. Nimisha et al. proposed an energy efficient connected dominating set using the Ant Colony Optimization (ACO) technique [20]. In another research, Mohajer et al. presented a heuristic selecting Connected Dominating Set (CDS) based on weighing factors in order to activate an intrusion detection system for the limited number of nodes [21]. More et al. also studied the optimal sleep schedules for redundant nodes using their neighboring active nodes' battery discharge rate, failure probability, and coverage overlap information [22]. In addition, a Routing algorithm in order to maximize lifetime in WSN has been proposed by Lipiński et al. [23]. Each network consists of a large number of sensor nodes that are used for collecting and processing data. Due to the small size and low cost of sensor nodes, different WSNs are used for different applications. Shi et al. investigated a single-link and multi-link failure in WSN using network graph decomposition [24]. Additionally, Chen et al. studied the maximum lifetime and range adjustable in WSN using a neighbourhood-based estimation [25]. All of these studies show the interesting idea of this research. The next sections of this article are organized as follows. First, the system model is introduced and the basic algorithm is reviewed in section 3. In section 4, the proposed algorithm is described in detail. We will present a proposed scheme. In section 5, the evaluation and operation and its results are compared and described. Finally, a general conclusion is presented.

3. System Model

In this sequential based on backbone network, a number of nodes are selected as the backbone of the network and the rest of the nodes are connected to each other through these nodes belonging to the backbone. Definition of connection control: If we define the network connection as a graph $G = (V, E)$, the set V contains active nodes in the network, and for the vertices, u and v belong to the V edge (u, v) belongs to the set E if and only if there is a direct connection between nodes u and v. The correlation control is then to find a connected subgraph called $T = (VT, ET)$ of G such that $VT \subseteq V$ and $ET \subseteq E$. Definition of Dominant Set (DS): For graph $G = (V, E)$ which represents the network correlation, the dominant set is defined as follows. The subset D of V is a dominant set if each node v belongs to V in D or is a neighbor in D, which can be expressed as Equ. (1) [14].

$$\forall v \in V: v \in D \vee \exists d \in D: (v, d) \in E \quad (1)$$

Definition of a Connected Dominant Set (CDS): A subset of C from V is called a CDS, if C is a dominant set and causes a connected subgraph to form G. As a result, nodes belonging to C can communicate with each other without using nodes belonging to the set V - C. In practice, nodes belonging to the CDS form a set of nodes in the network, the smaller the number of nodes, the better the correlation control. Given that the problem of finding the optimal CDS is an NP-hard problem [15]. As a result, many innovative methods have been proposed to find the optimal CDS, one of which is the tree growth method [13, 21].

3.1. Tree growth algorithm

The idea of this algorithm is to build CDS as a spanning tree. Add nodes and edges to the tree until all nodes are covered. The algorithm detects CDS using node coloring: white nodes are not yet processed, black nodes belong to CDS, and gray nodes are nodes that are connected directly to one of the nodes belonging to CDS. In practice, this algorithm takes the graph $G = (V, E)$ as input and finds the CDS by coloring the nodes. The implementation of this algorithm is shown in Figure 1. The CDS generated by this algorithm may not be optimal. As shown in Figure 1, the optimal CDS is $\{E, F\}$, While this algorithm specifies $\{A, B, D\}$. As CDS.

Selecting a gray node to a black node is a critical step in the tree growth algorithm. Therefore, to get a better CDS, you have to choose the node to black out intelligently. Hence, the tree growth algorithm is cleverly presented in this section. Which is presented in Section 4-1 of the Greedy Tree Growth Algorithm and in Section 4-2 of the Greedy Tree Growth Algorithm based on looking forward.

3.2. Greedy Tree Growth Algorithm

An interesting initiative for selecting the next black node is the selector that turns more white nodes into gray [6]. This greedy initiative finds the optimal CDS for the graph shown in Figure 1. However, there are simple graphs that show the error of this initiative. Consider the graphs shown in Figure 2. By running the greedy algorithm on this graph and starting from node u, the number of CDS nodes will be d + 2. Whereas, the optimal CDS has four nodes (u, v and two nodes of horizontal lines).

3.3. Greedy algorithm based on looking forward

The short-sightedness of greedy tree growth can be solved by looking forward, which acts on the basis of predicting the effect of selecting each node. This algorithm performs the following calculation for each gray node and is selected based on which node is more effective and turns into a black node. For each gray node and each of its white neighbors, it is assumed that the gray node and its neighbor white node are converted to a black node, calculating how many nodes are converted to gray. By doing this calculation, for each gray node, the nodes of this step, first identify all of the two subsets of the BNS set, after that, examines each subset of two Member, whether there is a path between the two members through the BNC set in the graph. If there is no path, it finds all the paths between these two members in the graph and calculates the cost of each path using Equ.(2).

$$\textit{Path cost=length of path-}\ (2 \times number\ of\ Black\ node\ in\ the\ path) \quad (2)$$

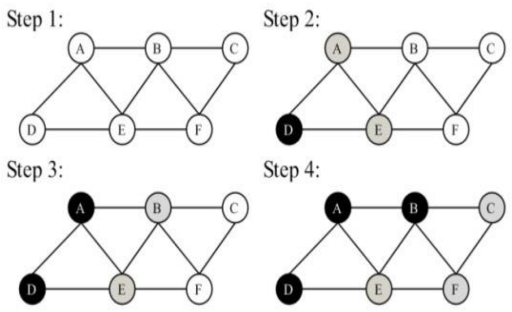

Figure. 1. Execution of tree growth algorithm

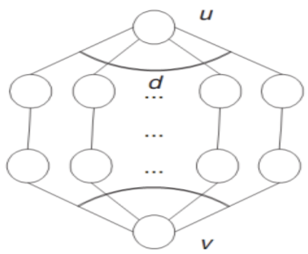

Figure. 2. Graph showing the error of the greedy tree growth method [4].

Steps of implementing the greedy tree growth algorithm based on looking forward is as follow:

Step 1: Select Node A. The result of this step is shown in Figure 4.

Step 2: From nodes B, C, and D, node B is selected. Because, according to the greedy algorithm based on looking forward, node B has more value. The result of this step is shown in Figure 5.

Step 3: From nodes C, D, and E, node E is selected. Because, according to the greedy algorithm based on looking forward, node E has more value. The result of this step is shown in Figure 6.

Step 4: From nodes C, D, F, H, and I, node H is selected. Because, according to the greedy algorithm based on looking forward, node H has more value. The result of this step is shown in Figure 7.

Step 5: From nodes C, D, and J, node J is selected. Because, according to the greedy algorithm based on looking forward, node J has more value. The result of this step is shown in Figure 8.

Because there is no white node, the algorithm ends and the CDS will be as follows.

CDS = {A, B, E, H, J}.

4. Proposed Algorithm

The proposed algorithm is based on the tree growth method, which works in a good way and adds nodes to the CDS. First, we describe the steps of this algorithm, and in the following; our proposed algorithm steps are explained. The tree growth algorithm works to obtain CDS as follows.

Step 1: Turn the node that has the most neighbors (or in other words has the most degrees) to black.

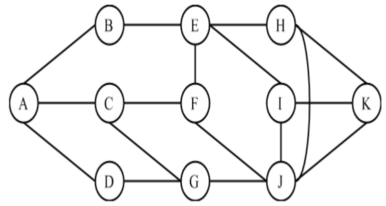

Figure. 3. Graph to compare the proposed algorithm with the greedy tree growth algorithm based on looking forward

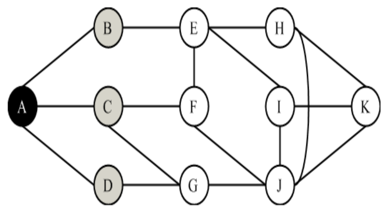

Figure. 4. The result of the first step

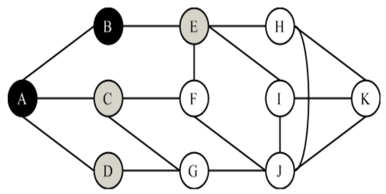

Figure. 5. The result of the second step

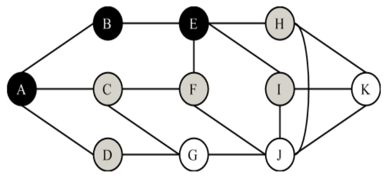

Figure. 6. The result of the third step

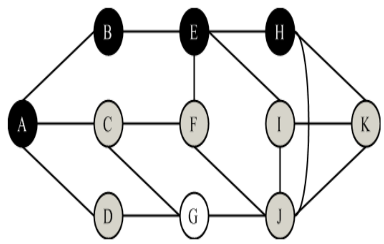

Figure. 7. The result of the fourth step

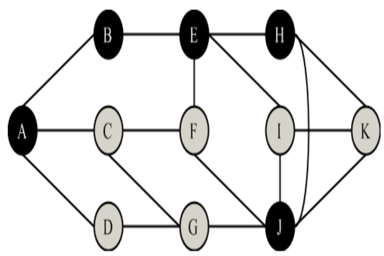

Figure. 8. The result of the fifth step

Step 2: From the non-black nodes, a node is selected for blackening, the value of which is higher than the other nodes according to Equ.(3). This step continues until there are no white nodes left.

$$value\ (v \in V) = \begin{cases} 2 \times (\text{Num of white neighbor Node } v) \\ -\frac{1}{4}\sum distance\ of\ v\ node\ from\ black\ non\ neighbor + 1\ , v\ is\ white \\ 2 \times (\text{Num of white neighbor Node of } v) + 2 \times (\text{Num of black neighbor Node of } v) \\ -\frac{1}{4}\sum distance\ of\ v\ node\ from\ black\ non\ neighbor \\ , v\ is\ black \end{cases} \quad (3)$$

At the end of this step, a set of Black Nodes (BNS) is formed.

Step 3: After the end of the second step, the subgraph obtained from the main graph may not be connected, that is, there may be no path between the two vertices belonging to it. Doing this step ensures that the subgraph obtained from the second step becomes a connected subgraph.

It selects any less expensive path as the path between the two nodes and blackens all non-black nodes within this path and adds it to the BNS set.

Our proposed technique is described in detail as the proposed scheme in Figure 9.

The steps of implementing the proposed algorithm on the graph of Figure 3 are as follows:

Step 1: Node J is selected with the highest degree (neighbor). Figure 10 shows the result of the first step.

Step 2: This step should be done as long as there is a white node.

First time: The number of nodes that can be selected for the black node is calculated using Equ.(3), where the amount of node A is more than the other nodes, so it is selected and blackened. Figure 11 shows the result of this selection.

Because there is a white node, the second step continues. The second time: the amount of nodes that can be selected for the black node is calculated using Equ.(3), where the value of node F is more than the other nodes, so it is selected and blackened. Figure 12 shows the result of this selection.

According to Figure 12, there are no white nodes left, so the second stage ends, and the set of black nodes is obtained as follows:

Black Nodes Set (BNS) = {A, F, J}

Step 3: In this step, we have to get the two-member subsets of the BNS set obtained from the second step, which will be as follows:

{A, F}, {A, J}, {F, J}

Given that there are three subsets of two members, this step consists of three steps as follows:

1. Check whether there is a path between node A and node F through the nodes of the BNS set.

   According to Figure 12, there is no path between node A and node F through the BNS set. According to Figure 12 and Equ.(2), routes A, C, and F have the

Proposed Scheme

- *Begin;*
- *arrange all the nodes of the network graph 'G' in ascending order.*
- *check **maximum** neighbor nodes number;*
- *Check the fan out and fan in route of nodes;*
- *Sort sink node;*
  $\forall v \in V: v \in D \lor \exists d \in D: (v, d) \in E$
- *Find the energy of the V' vertices of the network graph 'G'*
- *Find the neighbor nodes of the sink node* N_{sn} $v_i, v_{i+1}, \ldots, v_n$
- *check the energy of the V' nodes of the network graph 'G'*
  $Veng = v_{1e}, v_{2e}, \ldots, v_{ne}$
- *classify the energy of all the set of nodes of graph 'G' in descending order.*

Calculate:
If vi(E)>vi+1(E) then,
vi(E) → Eni , vi(D)→Degi
else
put nodes to the BNS set; then,
vi+1(E) →ENi
vi+1(D) →Degi
If $v_i(E) == v_{i+1}(E)$ *then,*
If $v_i(D) > v_{i+1}(D)$ *then,*
$v_i(E)$ → *ENi* , $v_i(D)$ → *Degi*
else
$v_{i+1}(E)$ → *Eni* , $v_{i+1}(D)$ → *Degi*

- *repeat:*
  check the ***value*** $(v \in V)$ *AND path loss;*
  return :update the BNS set;

Figure. 9. Proposed Scheme

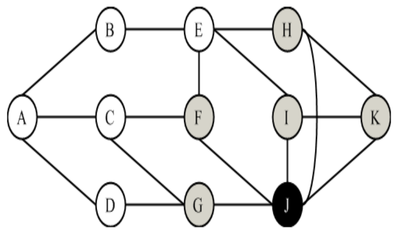

Figure. 10. The result of the first step.

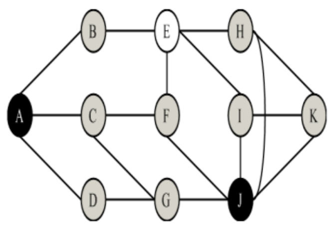

Figure. 11. The result of the second step, the first time.

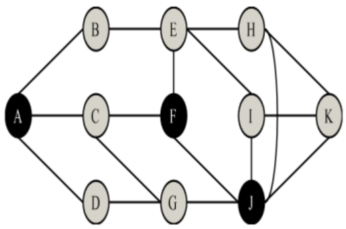

Figure. 12. The result of the second stage, the second time.

lowest cost. As a result, node C turns black and is added to the BNS setting. The result of this step is shown in Figure 13.

2. Check whether there is a path between node A and node J.

According to Figure 13, it can be seen that there is a path between nodes A and J through the BNC set.

3. Check whether there is a path between node F and node J.

According to Figure 13, it can be seen that there is a path between nodes F and J through the BNC set.

After the end of the third step, the result of which can be seen in Figure 13, the CDS is obtained as follows.

CDS = {A, C, F, J}

Figure 8, shows that the number of CDS members obtained through the greedy tree-based algorithm, based on looking forward is 5 while the number of CDS members in the optimal state is 4. Figure 13 shows that the proposed algorithm was able to obtain the optimal CDS. The above indicates that the proposed algorithm has been able to perform better than the greedy looking forward algorithm.

5. Evaluation and Results

In this section, the proposed algorithm is compared with the tree growth algorithm, the greedy algorithm based on looking forward, and the number of nodes belonging to the CDS is considered as an evaluation criterion. The comparison of the proposed algorithm with the greedy algorithm based on looking forward is investigated. Both algorithms find the optimal CDS for the graphs shown in Figures 2 and 3. Hence, to compare these two algorithms, Figure 3 is considered. According to the methods of the proposed algorithm, due to the selection of fewer nodes in the assessment of network connectivity, energy consumption will be reduced and as a result, the amount of energy remaining for each node and the entire network will be higher. Figure 14 shows the number of selected nodes in our proposed method. This indicates less energy consumption in the network. The result shows, according to the diagram, the number of selected nodes is less and the best node was selected to maintain connectivity in the growing network. Apart from improving and maintaining network connectivity, this is also effective in reducing battery consumption. Considering the selection of the lowest number of nodes in the evaluation of the network connectivity and the selection of the best route to connect to the next node, the duration of the evaluation is reduced and the shortest connected route is selected. As a result, this action causes less delay and less time to transfer information from one node of the network to the others at the end. In Figure 15, the reduction of power consumption is clearly shown. It is obvious that the remaining energy of batteries in each node is higher than the ordinary LFA algorithm. In Figure 16, the delay between nodes is depicted. It shows the lowest delay in each step of the proposed algorithm. In addition, it deals with low complexity and higher speed of selection in steps of our algorithm. In future research, we are trying to investigate the impact of attacks on the network and check the connection in the network with the presence of attacking nodes and their effects.In addition, the relay node and the cognitive radio network will

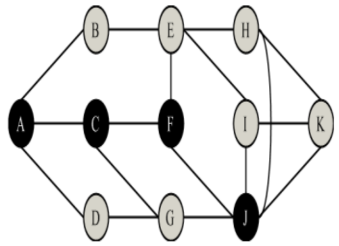

Figure. 13. The result of the third step.

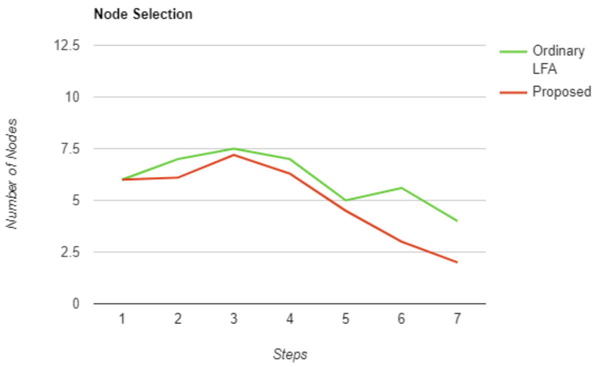

Figure. 14. Number of selection nodes in algorithms

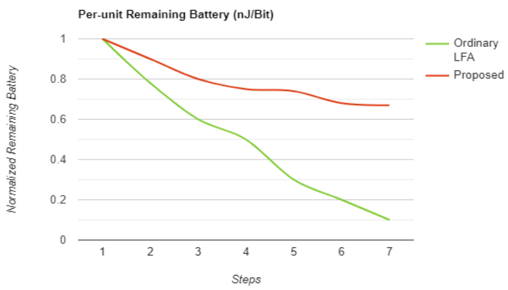

Figure. 15. Battery consumption and remaining

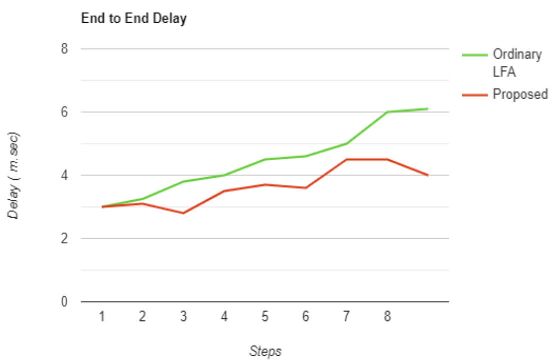

Figure. 16. Delay in Network

be investigated in order to approach the best network features. We try to check these networks by self-learning and intelligent evolutionary algorithms.

6. Conclusion

Due to battery limitations in wireless sensor network nodes, optimizing energy consumption in wireless sensor networks is essential. In this article, an attempt was made to design a connected network with the proposed algorithm. However, according to the simulations, the low power consumption of the network and the reduction of delay in the network are among the features obtained from the proposed algorithm. We introduced a new technique in the tree growth algorithm to determine the backbone of the network and compared it with the ordinary tree growth algorithm. The results of the comparisons indicate that the proposed algorithm works better in delay and power consumption in the network. In the future works, we will notice the existence of attacker nodes in the networks, especially, for the cognitive radio networking. One of the main type of attacks is the Byzantine attacks. We intend to investigate its effects on connectivity and sensor nodes failure, energy consumption and routing in the network using of the optimized evolutionary algorithms or the computer aided mechanism.

Declarations

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Authors' contributions

PDB: Study design, interpretation of the results, drafting and revising the manuscript, Supervision; AY: Study design, acquisition of data, interpretation of the results, drafting the manuscript, revision of the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

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