Hex-Grid Based Relay Node Deployment for Assuring Coverage and Connectivity in a Wireless Sensor Network

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Abstract: Efficient placement of relay nodes is an important issue in a two-tier wireless sensor network. This ensures the coverage and connectivity of the complete network with least number of relay nodes. Since the relay nodes are comparatively expensive than the sensor nodes, the overall cost of the network is also required to be maintained. In this proposal, we aim to propose an efficient relay node deployment scheme that results in a covered and connected network. The proposed scheme generates a set of positions by dividing the whole network area of interest into a hexagonal grid, where each vertex and the center is considered as the potential position for relay nodes. These positions are later optimized to find the optimal positions for the relay nodes. The algorithm runs in $O(n^2)$ time for n sensor nodes and is simulated to compare with the existing algorithms namely CRNSC and MRNCC. The result demonstrates a significant improvement of the proposed technique in terms of performance metrics like number of relay nodes required and performance ratio.

Keywords: Coverage, connectivity, deployment, hexagonal grid, relay node, wireless sensor network.

1. Introduction

Sensor networks have gained an enormous interest as a research area in the domain of wireless networks due to its wide range of applications like health care, disaster management, home automation, intrusion detection etc. [1-3]. Deployment of sensor nodes can be random or in specific positions depending upon its utility. Moreover, routing gathered data from sensor nodes (SNs) to sink may lead to energy depletion of sensor nodes. Hence, relay nodes (RNs) are required to form the upper tier in the network to relay information from sensor nodes which form the lower tier in the wireless sensor network (WSN) [4,5].

In recent years, there had been a continuous progress of WSNs, but still one of the crucial research challenge related to wireless sensor communication is to reduce the energy consumption of sensor nodes to enhance their lifetime and restrict the network cost in terms of hardware requirement [6,7]. Relay nodes having larger communication range and higher on-board power supply hence can be used for multi-hop routing to the sink [4-8]. The relaying of information from sensor node to sink via other relay nodes helps in energy conservation at sensor nodes and is depicted in Fig 1.



Fig. 1: Relay Node based network Architecture

RN placement in WSN aims to assure coverage of all the sensor nodes and at the same time maintaining the connectivity among RNs for a smooth communication [9,10]. For any sensor node, the term coverage refers to the scenario where it will have at least one RN within its communication range to which it can forward its sensed data. However, the term connectivity is associated with RN to RN which present a scenario where each RN will have at least one other RN to which it can relay the aggregated data. In this paper, we proposed an efficient RN deployment scheme which uses hexagonal grid pattern for initial positioning of RNs. Further, the RN count is optimized to assure coverage and connectivity with the time complexity of $O(n^2)$ where *n* is the total number of SNs. The proposed deployment scheme is simulated and compared with existing algorithms namely CRNSC [9] and MRNCC [16] to observe the efficiency of the proposed algorithm.

The rest of the paper is organized as follows. The background literature related to RN placement is discussed in Section 2. The system model to be used for the implementation of proposed deployment is described in Section 3.

Section 4 presents the proposed Hex-grid based RN deployment scheme for WSN with the detailed procedure. Simulation results and performance evaluation between proposed and existing algorithms is presented in Section 5. Finally, Section 6 concludes the paper.

2. Related Works

Relay node deployment has been an eye of interest from past many years as it directly affects the network performance in terms of communication, connectivity, coverage among the sensor nodes [1,4,5,8,9]. In order to cover the disconnected node pairs in WSN, a 2-dimensional unique relay node placement technique is used which can be useful for radio environments having problems related to path loss, shadowing, and multipath fading effects [11]. In another approach, a two-tier hierarchy of WSN is created where relay nodes are modelled as cluster heads of sensor nodes [12]. Here, a linear programming based relay node placement technique is used that not only covers the sensor nodes but also provides load balancing within the WSN. Using same concept of linear programming, authors in [13] introduced a partition based algorithm to place the relay nodes and further optimize the number using convex optimization method. Optimized relay node deployment is presented in [14,15] which focusses on energy efficient RN placement and used genetic algorithm and artificial bee colony concepts. In another concept of relay node placement [16], to assure coverage and connectivity, the relay nodes are placed in a spiral sequence focusing on the optimized deployment. Authors in [17] introduced the RN deployment in 4G mobile networks like LTE/LTE-Advanced and the mobile WiMAX networks. The main focus is given to the cost effectiveness during RN deployment using adaptive cost estimation thereby maintaining the

transmission quality and coverage parameters. In another approach of RN placement using artificial bee colony concept [18], further optimization in number of relay nodes is proposed thereby increasing the network lifetime. A novel placement strategy of relay nodes is discussed in [19] where the heuristic approaches of placement are proposed based on optimal solution. A hybrid technique using approaches like triangle selection, Minimum Spanning Tree (MST) triangulation and Delaunay Triangulation based optimization are used for RN placement. In another concept proposed in [20], three optimization models are introduced which not only aim to reduce the node count but also focus on the cost reduction. The models are based on the variation in the node density present within the network. A Jarvis March approach for RN placement is presented in [21] ensuring k-coverage of the sensor nodes and s-connectivity of the relay nodes in the network.

3. System Model

The network and energy model is assumed similar to that of discussed in [21] and [22] respectively.

4. Proposed RN Deployment Algorithm

In this proposal, we basically want to explore the idea of hexagonal grid [22] which demonstrates its effectiveness in solving disk coverage problem.

However, in our proposal, we aim to increase the number of potential relay node positions by considering not only the center of hexagons but also its vertices, refer Fig. 2.



Fig. 2: Hex-grid formation over the target area with their center and vertices as the potential RN Positions

We then optimize these positions by selecting their smallest set which ensures complete coverage of the target area. The step by step presentation of the proposal in presented as Algorithm 1and this algorithm runs in O(n2) time where n is the number of sensor nodes. We also try to illustrate the algorithm is Fig. 3, where the complete process is described in 6 steps. The process begins with dividing the network area into a hexagonal grid.

Algorithm 1: Hex-Grid based Algorithm

Input: Position co-ordinates of sensor nodes. *Output*: Relay Node positions.

- **Step 1:** Divide the area of interest into hexagonal grid and extract its center and vertices as the potential positions for relay nodes.
- Step 2: Find the number of sensor nodes covered under each relay node position.
- Step 3: Select the position covering the maximum sensor node as the first position for relay node.
- Step 4: Remove all the sensor nodes covered by the selected relay node position from its set.
- Step 5: Repeat step 2 through step 4 until all the sensor nodes are covered.



Fig. 3: Illustration of Hex-Grid based algorithm where (a) divides the target area into hexagonal grid (b) the center and the vertices are considered as the potential positions for RN (c) Sensor nodes deployed in the target area (d) Potential relay node with maximum covered sensor nodes is finalized as first RN position (e) Covered sensor node in previous step are removed from its set and next best position for RN is searched (f) All RN position covering more than one sensor nodes are selected

5. Simulation Results

The simulation for the proposed algorithm was carried out over Matlab R2013a. Moreover, for a given set network parameters and considering random deployment of sensor nodes, the network can have different topology for each run hence the result presented for each scenario is an average ten different runs. The simulation result were then compared with the recorded data of existing algorithm CRNSC [9] and the optimal solution calculated using CPLEX as given in [23]. The results were also compared with another existing algorithm named Minimum Relay Node Connected Cover (MRNCC) [16]. A simulation instance of the proposed algorithm is presented in Fig.4, where 400 SN are deployed in a 480×480 m² network area with communication range, r = 40 m.



Fig. 4: Simulation instance

All the comparisons were carried over the metrics like, number of relay node required. The rationality behind this is that, our objective was to minimize the number of RNs necessary for the covering the whole network which further reduces the network cost. This comparison is also carried out in terms of network lifetime. We simulated the proposed algorithm over similar network scenario as in [10]. The simulation result is presented in Table 1.

The proposed algorithm was then compared with another algorithm named MRNCC. The comparisons were carried out over two different performance metric and the grid based algorithm marginally overpower the existing algorithm. Fig. 5 and Fig.6 demonstrate the effectiveness of the proposed algorithm.

The rationality behind this is the excess of potential RN positions which gives a larger option for relay node placement.

Comparison			
	(500, 24)	(400, 30)	(400, 40)
Algorithm	No. of relay nodes		
Hex-Grid Based	98	66	47
CRNSC	105	67	48
Optimal	84	57	39
	Performance ratio		
CRNSC	1.25	1.175	1.23
Hex-Grid Based	1.16	1.157	1.20

TABLE I: Comparison Result with Crnsc



Fig. 5: Comparison results in terms of RN required and network lifetime with various node densities



Fig. 6: Comparison results in terms of RN required and network lifetime with various communication ranges

6. Conclusion

In this proposal, we presented a hexagonal grid based relay node deployment scheme to assure complete coverage and connectivity of the network. Here target area was divided into hexagonal grid where each hexagonal vertex along with their center are considered as the potential relay node position. These positions are latter minimized to obtain the final position of relay nodes. The algorithm runs in $O(n^2)$ time for n sensor nodes and have recorded marginal improvement over existing algorithms. In future, we would like to use this algorithm to assure k-coverage and s-connectivity over the complete network.

7. References

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