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A Grid-Based Node Selection Approach for Complete Area Coverage in WSN

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Abstract: In today's era, area coverage in WSN is one of the most important research areas due to its wide range of applications. There are several strategies for area coverage. Among those, the grid-based approach has been proposed in the recent past that provides a better way to select the active nodes from grids rather than randomly selected from the whole deployed area. Nevertheless, this approach undergoes several limitations like deciding the size of the grid and selection of nodes from grids. In this paper, the main objective of the proposed approach is to find a better way to divide the deployed area into a number of grids and select the nodes from those grids with a goal to avoid coverage hole. In this approach, the grids are of the same size depending upon the sensing radius of the sensor node, i.e. the diagonal of each grid is equal to the sensing radius. According to Pythagorean Theorem, the length of each grid is (l=r/√2). Based on grid division, several possibilities are taken into consideration in order to achieve the grid area coverage with the help of neighbor nodes present in the surrounding grids. Simulation studies show this approach performs better than the existing grid-based approaches.

Index Terms: Area coverage; Grid-based approach; Wireless Sensor Network.

I. INTRODUCTION

Wireless Sensor Network (WSN) a has wide range of applications used in several domains like military, medical, object tracking, environmental monitoring, etc. WSN consists of a large number of sensor nodes that organize among themselves to sense the environment, perform processing of data and communicate the processed data to the base station. As sensor nodes main functionality is to sense the environment, so, coverage is one of the most important issues in WSN [2] which needs to be handled. Coverage can be classified into three types such as area coverage, point coverage, and barrier coverage. This paper focuses on area coverage in WSN. The main objective of area coverage is to cover the area. There are various strategies for area coverage that includes force based, grid-based and computational geometry based. Although all these three categories have their own advantages and disadvantages, in this paper, the proposed approach is based on a grid-based approach. The significance of the grid-based approach is that it is easier to select the nodes from the grids for the whole network. The ultimate objective of this approach is that in what way the deployed area will be divided into a number of grids and what is the selection criteria for nodes from each grid [1].

In our proposed approach, the whole area is divided into a number of uniform grids. Once, the area gets divided into a certain number of grids, and then from each grid, one node is selected. All these grids may not be uniform because grids are divided on the basis of the radius of the nodes. Here, the radius of the node is considered as the diagonal of the grids. The rest of the paper is systematized as follows. Section 2 describes the survey related to the area coverage in WSN. Details of the proposed approach are discussed in Section 3 which is followed by the performance of the proposed work along with the comparison with existing work in Section 4. At last, Section 5 concludes the work.

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II. LITERATURE SURVEY

In WSN, energy conservation is an important issue because the battery is important equipment of sensor nodes which have limited lifetime. It is impossible to recharge the battery when these are deployed randomly. So, prolonging network lifetime is the main challenge. In order to increase the lifetime of WSN, efficient resource management and active nodes selection for sensing coverage are two fundamental requirements in a wireless sensor network. Sensing coverage in WSN is of three types namely area coverage, point coverage, and barrier coverage. In this paper, we have focused on area coverage [3].

Area coverage relates to how each point in the sensing field is covered. When each location of sensing field is covered by at least one sensor node then it is called I-Coverage and when each location is covered by K number of sensor nodes, where $K > 1$, then it is called K-Coverage. In WSN, full coverage is widely used. K-coverage is used in critical situations like military and health where node failure cannot be tolerated [7].

The main objective of the deployment strategy is to provide full coverage of the deployed area. Therefore, area coverage in WSN can be achieved by applying forces-based strategy, grid-based strategy, or the computational geometry-based strategy. Among these three strategies, the proposed approach focuses on grid-based strategy. There are four types of grid layout such as triangular grid, square grid, hexagonal grid and rectangular grid [1] [4].

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A. *Square grid*

In a square grid, the region of interest is divided into square cells. One sensor node covers a maximum one cell. If an empty cell appears, then the sink node takes a decision which node will move in order to cover the empty cell.

B. *Triangular grid*

In a triangular grid, the target region is divided into triangular shaped cells which cover the sensing area.

C. *Rectangular grid*

In a rectangular grid, the target region is divided into rectangular shaped cells, where this cell is represented as a sensing range of the sensor node.

D. *Hexagonal grid*

In this approach, the target region is divided into hexagonal shaped cells. Sensor nodes create a hexagonal cell in a distributed manner.

Triangular grid is the best deployment method because it has the smallest overlapping area and this grid requires the least number of sensors to cover the area. Hexagonal grid is the worst among all grid layout because it has the biggest overlapping area. A square grid provides overall good performance according to various studies [4]. The proposed approach uses the Square grid method.

According to various studies [8-11] besides the types of deployment, the size of the grid plays an important role in WSN. Small grids help in reducing the coverage hole and provide better area coverage in a dense network. But in a sparse network, large size grid is better because it helps in reducing overlapping of sensors sensing range, which ultimately provides full utilization of the sensor's sensing capabilities.

In a grid-based sensor network, the region of interest is divided into square grids and sensors are placed at the center of the square. The percentage of area covered in grid-based deployment is the ratio between the number of grids covered and the total number of grids.

III. PROPOSED APPROACH FOR COMPLETE AREA COVERAGE

In the proposed approach, the deployed area is divided into a number of grids on the basis of sensing radius [5] [6]. The diagonal of the grids are equal to the sensing radius. Hence, the length (l) of the square grid according to Pythagoras theorem is

$l =$ (1)

where,

l = Length of the grid

r = Sensing radius of the sensor node

Here, the grids are of uniform size except for some grids near the boundary portion as the deployed area is not perfectly divided based on sensing radius. In figure 1, grid number 1, 2, 3, 4, 6, 7, 8, 9, 11, 12, 13 and 14 are of uniform length and breadth but grid number 5, 10, 15, 16, 17, 18, 19 and 20 are not uniform length and breadth. In this proposed approach, one node from each grid gets selected for complete area coverage.

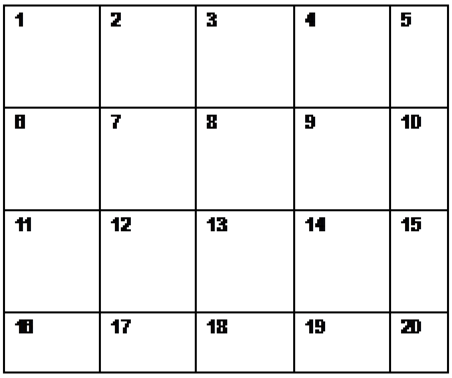

Fig. 1 Non-uniform grid near the boundary portion

If no node is present in a particular grid then some node is selected from the neighboring grid to cover the grid. The neighbors are named as follows. In figure 2, grid 4 and 12 are called as '*forward diagonal neighbors*' of grid 8, and grid 2 and 14 are called as '*backward diagonal neighbors*' of grid 8. Similarly, Grid 3 and 13 are called as '*vertical neighbor*' of grid 8 and grid 7 and 9 are called as '*horizontal neighbor*' of grid 8. Grid number 1, 2, 3, 4 and 5 are named as '*upper boundary region*' of the area. Similarly, grid number 16, 17, 18, 19 and 20 are named as '*lower boundary region*', grid number 5, 10, 15 and 20 are named as '*right boundary region*' and grid number 1, 6, 11 and 16 are named as '*left boundary region*'.

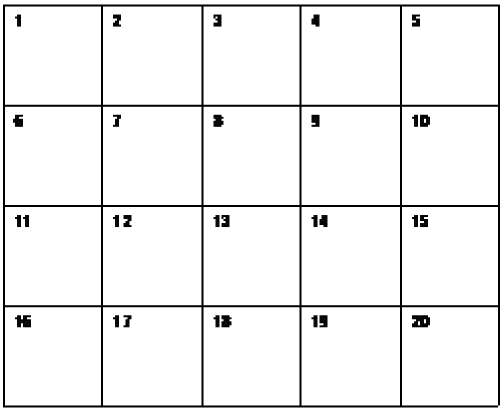

Fig. 2 Neighboring grid

While selecting a node from the grid which does not have any node or no node is currently active in that grid, there arise two instances.

Case 1: When any grid near the boundary region of the deployed area is currently empty:

Here, there exist two cases.

Grid is nearer to the left or right boundary region:

The nodes are selected from the grids of vertical neighbors with conditioned that grid nearer to the left or right boundary is empty. For example, in Figure 3, if grid 6 is empty then nodes are selected from the vertical neighbor of grid 6, i.e. from grid 1 and 11. Similarly, if grid 10 is empty then nodes are selected from grid 5 and 15.

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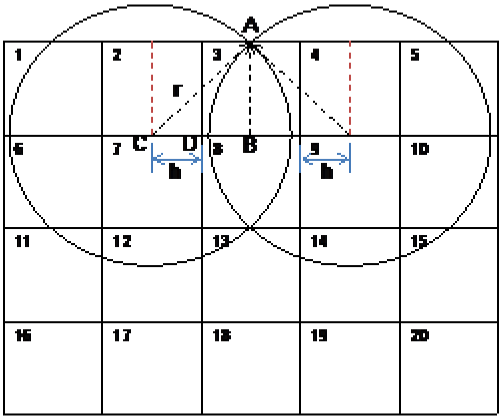

Fig. 3 Selecting node from neighboring grids near upper and lower boundary region

b) Grid is nearer to the upper or lower boundary region:

The nodes are selected from the grid of horizontal neighbors with conditioned that grid near the upper or lower boundary is empty. For example, in figure 3, if grid 3 is empty then nodes are selected from the horizontal neighbor of grid 3, i.e. from grid 2 and 4. Similarly, if grid 17 is empty then nodes are selected from grid 16 and 18.

Further, there is a restriction while selecting a node from those grids. This restriction is set to avoid coverage hole in WSN. The node selected from the neighboring grid should cover at least half of the area of the empty grid so that node selected from the other neighboring grid will cover the rest of the uncovered area. To select such a node that will cover at least half of the grid area, the range is derived as follows.

In figure 3,

$$AC^2 = AB^2 + BC^2$$

$$\Rightarrow r^2 = \left(\frac{r}{\sqrt{2}}\right)^2 + BC^2$$

$$\Rightarrow BC^2 = r^2 - \left(\frac{r}{\sqrt{2}}\right)^2$$

$$\Rightarrow BC^2 = \frac{r^2}{2}$$

$$\Rightarrow BC^2 = \frac{r}{\sqrt{2}}$$

$$\Rightarrow BD + DC = \frac{r}{\sqrt{2}}$$

$$\Rightarrow DC = \frac{r}{\sqrt{2}} - BD$$

$$\Rightarrow DC = \frac{r}{\sqrt{2}} - \frac{r}{2\sqrt{2}}$$

$$\Rightarrow DC = \frac{r}{2\sqrt{2}}$$

$$\Rightarrow h = \frac{r}{2\sqrt{2}}$$

A node is selected from neighboring grid if it lies within a distance $h = \frac{r}{2\sqrt{2}}$ from the boundary of the empty grid. If a node is selected beyond this distance, there might be coverage hole in the empty grid. If there is no node present between the boundary of empty grid and distance 'h' from boundary, then one node from all the neighboring grids of the empty grid are selected, i.e. in figure 3, one node each from grid number 2, 7, 8, 9 and 4 are selected to avoid the coverage hole in grid 3.

Case 2: When any grid other than the boundary region of the deployed area is empty:

In this case, the nodes are selected from both horizontal and vertical neighbors of the empty grid. For example, in figure 4, if grid 8 is empty then nodes are selected from the horizontal neighbors of grid 8, i.e. from grid 7 and 9, and nodes are also selected from the vertical neighbors, i.e. from grid 3 and 13. Like earlier discussion in the previous case, there is also a restriction needs to be set for the same purpose with different criterion. The node selected from each neighboring grid should cover at least one-fourth of the empty grid so that the complete area is covered by four neighbors of the empty grid. The range from which node can be selected is derived as follows.

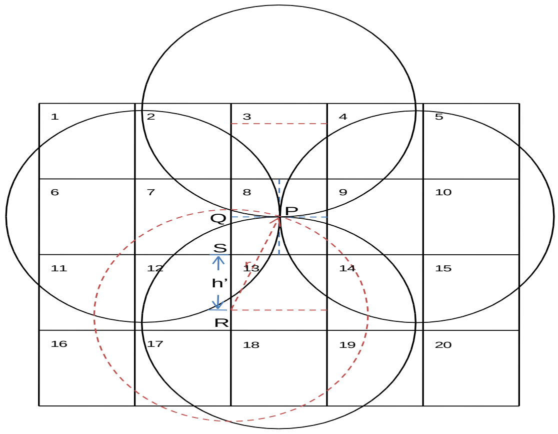

Fig. 3 Selecting node from neighboring grids near left and right boundary region

In figure 4, $PQ = \frac{r}{2\sqrt{2}}$ (half of the side of the square), $QS = \frac{r}{2\sqrt{2}}$ (half of the side of the square), $PR = r$ (radius of the node).

$$PR^2 = PQ^2 + QR^2$$

$$\Rightarrow r^2 = \left(\frac{r}{2\sqrt{2}}\right)^2 + QR^2$$

$$\Rightarrow QR^2 = r^2 - \left(\frac{r}{2\sqrt{2}}\right)^2$$

$$\Rightarrow QR^2 = r^2 - \frac{r^2}{8}$$

$$\Rightarrow QR^2 = \frac{7r^2}{8}$$

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$$\Rightarrow QR = \left(\frac{7}{8}\right)^{\frac{1}{2}} r$$

$$\Rightarrow QS + SR = \left(\frac{7}{8}\right)^{\frac{1}{2}} r$$

$$\Rightarrow SR = \left(\frac{7}{8}\right)^{\frac{1}{2}} r - QS$$

$$\Rightarrow SR = \left(\frac{7}{8}\right)^{\frac{1}{2}} r - \left(\frac{1}{2\sqrt{2}} r\right)$$

$$\Rightarrow SR = \left(\frac{7}{8}\right)^{\frac{1}{2}} r - \left(\frac{1}{8}\right)^{\frac{1}{2}} r$$

$$\Rightarrow SR = \left(\frac{\sqrt{7}-1}{8}\right) r$$

$$\Rightarrow h' = \left(\frac{\sqrt{7}-1}{8}\right) r$$

Node is selected from neighboring grid if it lies within a distance $\Rightarrow h' = \left(\frac{\sqrt{7}-1}{8}\right) r$ from the boundary of the empty grid. If a node is selected beyond this distance, there might be coverage hole in the empty grid. If no node is present between the boundary of empty grid and distance from boundary, then one node from all the neighboring grids of the empty grid is selected i.e. in figure 4, one node each from grid number 2, 3, 4, 9, 14, 13, 12 and 7 are selected.

Once the nodes are selected from each grid, based on coverage criteria, the redundant nodes are removed. In order to increase the network lifetime, this process is continued for several numbers of rounds. After the completion of each round, the active node goes to sleep state. Further, a similar mechanism is carried out with the remaining nodes. This process continues until all the available nodes achieve the complete area coverage.

IV. PERFORMANCE RESULT

The performance of the proposed protocol is studied using Matlab simulator. In this simulation study, we have considered the sensing radius of each sensor node to be 4m. We have considered a different number of nodes in different simulations by changing the deployment area to find the number of active nodes. We also found the number of redundant nodes. Besides these, we compare the performance of the proposed approach with the existing distributed randomized grid-based approach [6].

Figure 5 shows how the number of active nodes changes with change in the total number of nodes and deployment area. As the size of the deployed area increases, more number of active nodes is required to cover the deployed area. The number of active nodes increases when the deployment area as well as the total number of nodes increases.

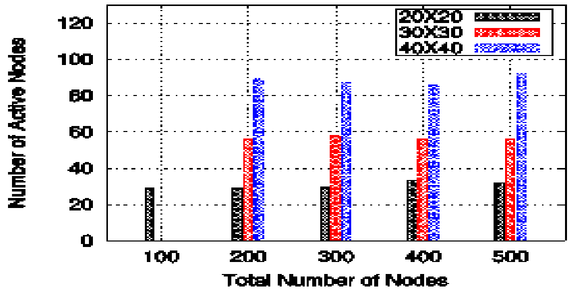

Fig. 5 Active nodes with respect to the total number of nodes and different deployment area

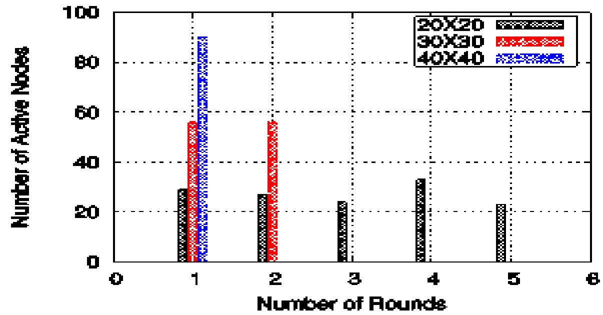

Fig. 6 Active nodes versus the number of rounds when 200 nodes are deployed

Figure 6, 7, 8, and 9 show the number of active nodes selected in different rounds of simulation with 200, 300, 400, and 500 number of nodes respectively. Each figure depicts the number of active nodes selected to cover the deployed area of size 20X20, 30X30 and 40X40. From these figures, we can conclude that with more number of sensor nodes and less deployed area, the selection of active nodes can be continued for more number of rounds. This is because the nodes selected in any round are discarded from the participation of the selection process of the nodes in the next round. Once the remaining nodes are not able to cover the whole deployed area then all the nodes once again participated in the selection process for achieving complete area coverage. Like in figure 6, with 20X20 deployed area and 200 number of nodes, the active nodes can be selected up to 5 rounds whereas with 20X20 deployed area and 500 number of nodes, as shown in figure 9, the active nodes selection can be continued up to 10 number of rounds. Similarly, with larger size deployed area and less number of nodes, the active nodes selection is continuing for less number of rounds.

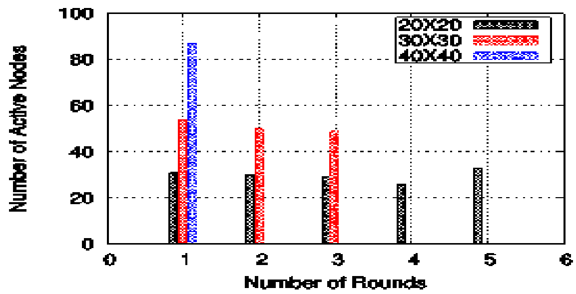

Fig. 7 Active nodes versus the number of rounds in 300 nodes

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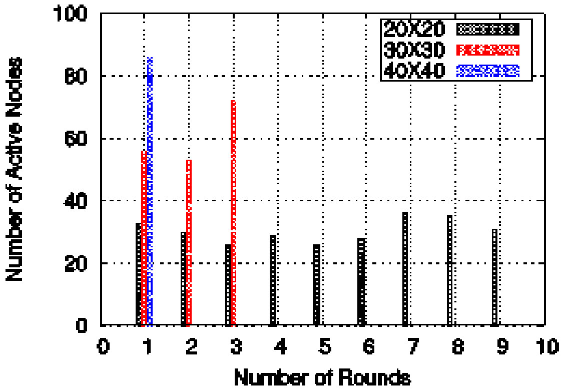

Fig. 8 Active nodes versus the number of rounds when 400 nodes are deployed

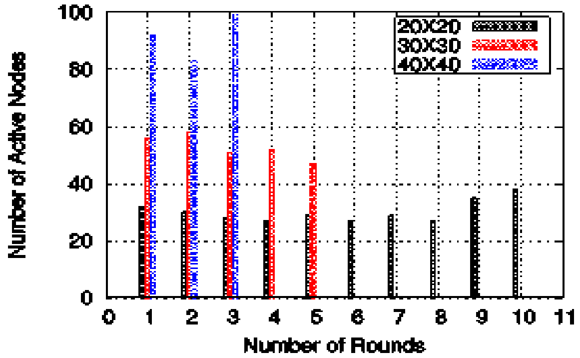

Fig. 9 Active nodes versus the number of rounds in 500 nodes are deployed

Figure 10, 11, and 12 show the comparison with respect to the number of active nodes in different size of the network in between distributed randomized grid-based approach and proposed approach with deployment area of size 20X20, 30X30, and 40X40 respectively.

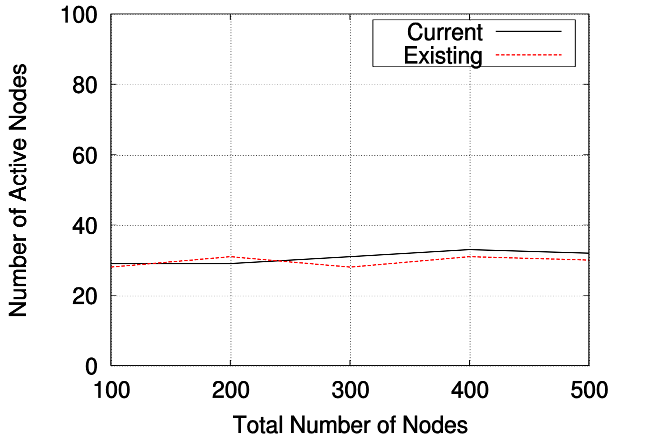

Fig. 10 Number of nodes versus active nodes in the deployed area of size 20X20

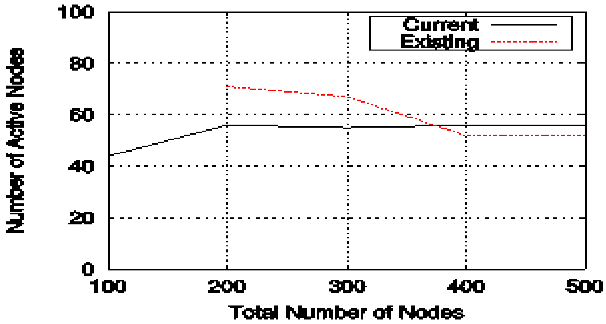

Fig. 11 Number of nodes versus active nodes in the deployed area of size 30X30

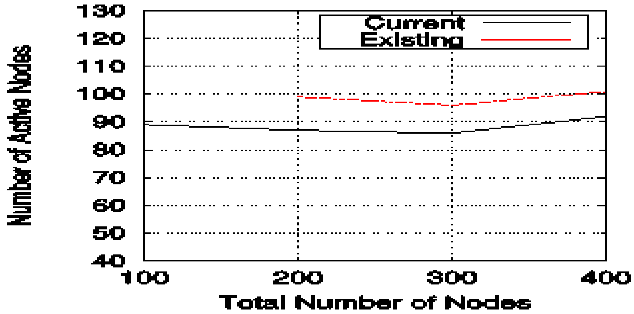

Fig. 12 Number of nodes versus active nodes in the deployed area of size 40X40

In figure 10, the number of active nodes in the current and existing approach is almost the same. But in figure 11, in some of the cases, less number of nodes is required in the current approach as compared to the existing approach. Whereas, in figure 12, in all cases, the number of active nodes is much less in the proposed approach as compared to the existing approach. It is observed that with an increase in the deployment area the number of are less in the current approach as compared to the existing approach. In the current approach, when the deployment area is of large size, as the grid size are fixed there will always be a fixed number of grids for a particular area. But, in the case of existing approach, more number of grids will be created. This, in turn, leads to more number of active nodes. Again, when the deployment area is of small size, the density is more as compared to large size area. In our current approach, each grid is of the same size and number of grids are also fixed. So, when we select the nodes from each grid, the chance of redundancy is less. But in the case of the existing approach, more grids will be created in the denser area and hence redundancy will be more.

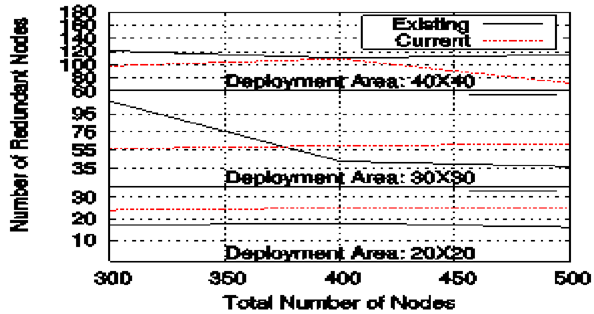

Fig. 13 Number of nodes versus redundant nodes

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Figure 13 depicts, with an increase in deployment area the number of redundant nodes also increases. In the deployed area of size 20X20, in the existing approach, the number of redundant nodes are less as compared to the current approach. In the deployed area of size 30X30, when 300 nodes are deployed, the number of redundant nodes in the existing approach is more as compared to the current approach. Whereas, when 400 or 500 nodes are deployed in the area, the number of redundant nodes are less in the existing approach as compared to the current approach. But, in the case of the deployed area of size 40X40, the number of redundant nodes is always less in the current approach as compared to the existing approach.

V. CONCLUSION

In this paper, a grid-based node selection approach is given for complete area coverage in WSN. The deployed area is divided into a number of grids on the basis of sensing radius. The grids are uniformly divided with diagonal size equal to sensing radius. In this approach, a node is randomly selected from each grid. If no active node is present in a particular grid then a node is selected from its neighboring grid with imposing a restriction to avoid the coverage hole. Further, if the area is still not covered by those nodes then nodes are selected from all the neighboring grids. After achieving area coverage redundant nodes are removed. This process continues till the whole area is covered. Simulation results show that the proposed approach's performance is better as compared to the distributed randomized grid-based approach in terms of the number of active nodes as well as the number of redundant nodes.

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