http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (23): 7466-7470, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.7466.7470

Research on Wireless Sensor Network Node Deployment and Recovery Based on 0-1 Programming Model

Wang Zhang-quan, Liu Ban-teng and Chen You-rong
Zhejiang Shuren University, Hangzhou, 310005, China

Abstract: This study attempts to study the problem of the deployment and optimization of sensor network node. Firstly, the author puts forward a deployment plan of sensor network node and the formula to calculate sensor node to complement the plan. Secondly, considering the necessity of repair when the coverage rate is lower than 85 percent, the author attempts to set up the restricted 0-1 optimization class model which minimizes the cost of the new deployment node pays. Finally, taking monitoring performance of network and the cost for repair into consideration, the author attempts to select the best program based on the plan and monitors the paths in the plan through shortest path algorithm one by one to know whether it satisfies the pathway condition or not until the plan is found.

Key words: Honeycomb grid, 0-1 programming model, shortest path algorithm

INTRODUCTION

As a new technology of information acquisition and processing, Wireless Sensor Network (WSN) is widely applied into such fields as defense and military, environmental monitoring, relief against terrorism and tracking which always uses wireless sensor to monitor the natural disaster (Anastasi *et al*., 2006). A considerable number of intelligent devices should be deployed which compose the monitoring system covering the whole areas so that the condition of disaster area could be observed and monitored instantly. The system is used to perceive the various changes of states nearby, whose ability of perception fades in accordance with the increasing distance between the node and the target (Busse *et al*., 2006). Due to the limited ability of perception and coverage for each node, a great number of nodes should be deployed in order to achieve the goal of area surveillance.

The general way to deploy sensor node is to carry out through airplane or robots. When the ratio of area perceived by nodes and total areas reach a certain value, the area could be considered as effective monitoring. The area which isn't covered by any node is called coverage hole. As long as the area is covered by any one or more nodes, it could be regarded as effective coverage. When the node is damaged by external interference or destruction, death or failure of node might also form coverage hole.

Deployment scenarios of sensor network node: AS regards to the coverage holes existing at random after the initial coverage, this study attempts to redeploy the wireless sensor via honeycomb grid model. This study presents a coverage rate of 100 percent in the sensor nodes deployment scenarios. And based on this, the author gives the corresponding coordinate through constantly reducing the number of cellular to satisfy the coverage rate of more than 95 percent and studying the relation between cellular coverage and the number of cellular (Baek and de Veciana, 2005).

For the sensor nodes with the sensing radius R_s, its extant of perception is a round which covers the cellular through inscribed regular hexagon (Yin and Lin, 2005). The minimum coverage of a dimensional area is the coverage without loopholes and with minimal repetitions which is made by coverage model of hexagonal node. Then the area without loophole is:

$$A_c = \frac{3\sqrt{3}}{2} r^2 (3L(L+1)+1)$$

The minimal repetition of coverage area is (Srinivasan *et al*., 2004):

$$A_{K\min} = (3L(L+1)+1)(\pi - \frac{3\sqrt{3}}{2})r^2$$

The minimum sensor nodes:

$$A_{K\min} = (3L(L+1)+1)(\pi - \frac{3\sqrt{3}}{2})r^2$$

Accordingly, the maximum coverage could be drawn by hexagonal honeycomb (Johnson *et al*., 2004). Then the nodes are as followed:

Corresponding Author: Wang Zhang-quan, Zhejiang Shuren University, Hangzhou, 310005, China

At this point, the coordinates of the node is:

(8.7,5.0)	(26.0,5.0)	(43.3,5.0)	(60.6,5.0)	(77.9,5.0)	(95.2,5.0)
(17.3,15)	(34.6,15)	(52.0,15)	(69.3,15)	(86.6,15)	
(8.7,35)	(26.0,35)	(43.5,35)	(60.6,35)	(77.9,35)	(95.2,35)
(17.9,50)	(34.6,50)	(52.0,50)	(69.3,50)	(86.6,50)	
(8.7,65)	(26.0,65)	(43.5,65)	(60.6,65)	(77.9,65)	(95.2,65)
(17.3,80)	(34.6,80)	(52.0,80)	(69.3,80)	(86.6,80)	
(8.7,95)	(26.0,95)	(43.5,95)	(60.6,95)	(77.9,95)	(95.2,95)

Boundary region with regular hexagon is reduced via Matlab and the coverage ratio could reach 95%-100%, then the relation between maximum coverage ratio of the node and the number of nodes is as followed:

No. of nodes	38	39	40	41
Coverage Ratio	94.54%	96.46%	97.32%	98.18%
No. of nodes	42	43	44	45
Coverage Ratio	99.04%	99.36%	99.68%	>=100%

From the data above, we can know that when the number of nodes is 38, the maximum coverage ratio of the detection zone is 94.54% by the way of honeycomb grid which is blow the requirement of 95%; when the number of nodes is 39, the maximum coverage ratio of the detection zone is 96.46% by the way of honeycomb grid which satisfies the coverage ratio in demand. Then the minimum number of nodes is 39.

MATHEMATICAL MODEL OF DETERMINE THE COVERAGE HOLE

When the coverage area of nodes is less than 85%, the coverage loophole should be filled to so that the network coverage area of this region is no less than 85%. Firstly, this study is in search of the coverage loophole through counting the joint detection probability of nodes based on which mobile node optimization strategy is selected based on the optimal probability (Foulds, 1984) . Taking minimal loss of energy and time due to the mobile node into account which is related with the moving distance of node, the author comes to the conclusion that the problem could be solved by using the shortest path algorithm.

Firstly, the goal of at least 85% for the network coverage area is reached by the mobile node and divides detection area into m×m parts of grids. Suppose that the unit area for each grid is 1 and then the joint detection probability of a point K is:

$$C_k(p) = 1 - \prod_{i=1}^{N+M} (1 - P_i)$$

If each grid is measured whether it is covered by node joint detection probability C(p), then coverage ratio is the ratio of the coverage area of sets of nodes A and d detection area of the total area A_s, that is:

$$R(p) = \frac{\sum_{i=1}^{m\times m} C_i(p)}{m \times m}$$

For the N static nodes and M dynamic nodes deployed at random within the target areas, the joint detection probability for all points could be counted through node perception model because the node detection probability shows approximate exponential form after the death of s ensor nodes at random (Garcia-Luna-Aceves and Roy, 2005).

Because detection probability of each location is continual and probability around the lowest point of probability is relatively low, regional network coverage could be improved through adjusting mobile node to the point of coverage loophole; In order to avoid that the mobile distance of each node is too large, we attempt to deploy a virtual node in the loophole during each round of counting (Wu and Bhargava, 2005). After counting, we will adjust all the mobile nodes to the virtual points, minimizing the average distance of nodes while maximizing the network coverage.

MATHEMATICAL MODEL IF REPAIR COVERAGE HOLE

The so-called node repair, is to satisfy a particular require by deploying sensor nodes through proper strategy within a certain area. When repairing nodes, attention should be paid to optimize the number of nodes and node distribution form, efficiently take advantage of limited resources in sensor networks and minimize network energy consumption (Anastasi *et al*., 2006).

In order to minimize the time and energy in the course of nodes deployment, the time required for mobile nodes to reach the end depends on the physical time required to move the node according to relevant reference. Most of energy consumption of the sensor nodes centers on the wireless communication which accounts for 80% of energy consumption of the whole sensor nodes. When the mobile distance of nodes gets longer, the communication energy of nodes consumption gets larger. All in all, the author makes sure whether the node moves or not by adopting Dijkstra algorithm to solve the problem of shortest path and the way of 0-1 planning. Under the condition of guaranteeing connectivity, the time and energy in the course of deployment are reduced by moving parts of nodes to the shortest distance, making the network coverage ratio exceeds 85% after repairing (Anastasi *et al*., 2007).

Considering regarding the original working node as the starting point of repairing, the author introduces variable 0-1.

$$a_{ij} = \begin{cases} 0, \text{ith node to jth hole} \\ 1, \text{otherwise} \end{cases}$$

Minimizing the cost of deploying nodes is to go through the shortest distance when deploying. When this issue is evolved into a constrained optimization problem, then the linear indicators is used to measure the size of the deployment costs. Firstly, the author determines the programming model:

$$f(x) = \min \sum_{j=1}^{k} a_{ij} d_{ij}$$

$$\text{s.t.} \begin{cases} \dfrac{s_1 \cup s_2 \cup \ldots . s_n \cup s_1^{'} \cup s_2^{'} \cup \ldots s_k^{'}}{s} \geq 85\% \\ a_{ij} = \{0,1\} \\ 1 \leq k \leq m \end{cases}$$

d_{ij} represents the distance between the starting point i to the empty node j which needs repairing; s_i represents the extent of perception of the ith node which originally did the normal work; s_i' represents the monitoring extent of coverage node j; k represents the number of nodes which needs repairing.

According to the above distance model, the optimal repairing plan could be know by software lingo. Due to the arbitrary death of nodes, this study simulates the distribution of nodes under the condition of 79% coverage. The following is the coordinates of the nodes under this condition:

50,40	41,51	68,45	58,60	50,22	67,20	79,31	95,25	86,10	69,3
43,5	57,5	103,10	97,37	87,45	98,52	80,58	97,65	70,64	84,76
96,86	82,89	91,97	65,80	70,95	53,95	40,90	25,90	17,93	5,95
8,80	105,75	81,92	86,10	98,7	24,5	7,5	8,35	9,50	7,65

Denote the node from left to right, from top to bottom as point (x_i, y_i).

Through the joint probability model, we could get the coordinates of virtual nodes. In the joint virtual nodes and static nodes, we can get the coverage of 85% to satisfy the repairing goals and the coordinate of virtual nodes is as followed:

62,33	55,5	23,74	37,76	52,76	24,58
40,63	24,41	20,24	35,18	37,33	8,20

Denote correspondingly the coordinates of nodes which need to be covered from left to right, from top to bottom as A-L. Take node 2 for example, we can get following kinds of repair ways in accordance with moving node 2 to coverage hole(virtual node) and meeting node locations. In this case, the distance from node 2 reaches corresponding position is:

Route	2→F	2→G	2→H	2→K
Distance	18.3	12.0	19.7	18.4

The total shortest distance is:

$$f(x) = \sum_{i=1}^{M} \sqrt{\left(x_{o,i} - x_{n,i}\right)^2 + \left(y_{o,i} - y_{n,i}\right)^2} = 68.4$$

From which we could determine and calculate the shortest time it takes and energy consumption.

In order to achieve the goal of getting the minimum cost of repairing under the condition of connectivity, that is to say, data center which requires the shortest distance to pass the signal from the nodes to basic point. This study lists several plans with relatively small repairing cost, from which the position of nodes could be determined:

$$f = \min \sum_{j=1}^{k} a_{ij} d_{ij}$$

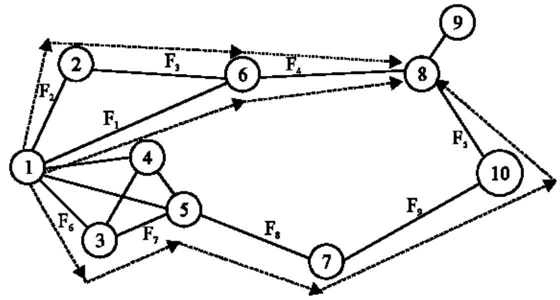
$$\text{s.t.} \begin{cases} \dfrac{s_1 \cup s_2 \cup \ldots . s_n \cup s_1^{'} \cup s_2^{'} \cup \ldots s_k^{'}}{s} \geq \alpha \\ a_{ij} = \{0,1\} \\ 1 \leq k \leq m \end{cases}$$

s_i represents the monitoring scope of nodes which can work normally before repairing; s_i' represents the detection range of nodes added in the place with coverage loophole; α represents the required coverage; k represents the number of repairing nodes.

With this model, based on the plan with desirable nodes, we detect it one by one by Dijkstra algorithm until we get the desirable plan. We could set up a weight matrix, supposing l_{ij} as the distance from vertex i to vertex j and weight matrix of picture G is $D^{(0)} = (d_{ij}^{(0)})$, then:

$$d_{ij}^{(0)} = \begin{cases} l_{ij}, (i,j) \in E \\ 0, i = j \\ \infty, \text{otherwise} \end{cases}$$

Based on it, solution could be gotten by Matlab. As the picture below has shown, we could roughly list the path selection from node 1 to node 8 which show the main idea of algorithm.



"Circle" represents the moving nodes; "-" represents communication link;

At this point, we still need to pick out the shortest path from the seven paths.

Compared the first one with the second one, we just need to compare the size of F1 and F2+F3. By this method, the shortest distance between two points is easily obtained. It generates small error, achieves program simply and determines the relationship between two points easily.

In addition, based on the shortest path acquired, we would also set up an optimized repair guideline. For the quadratic optimization of repairing guideline based on the shortest distance as the goal, the overlapping area between the sensors should be as small as possible: The overlapping area between sensor nodes should be as small as possible. Under the conditions of coverage are met, we also needs make a definition for coverage: the ratio of the total area with all nodes covered and the total area of target area which is an indicator to measured sensor network node deployment .Since the total area covered takes the collection in the concept of union, so the extent of coverage is generally less than or equal to 1:

$$C = \frac{\bigcup_{i=1...N} A_i}{A}$$

C represents the degree of coverage; A_i represents the number of nodes; A represents the area of the whole target area.

The goal is to minimize the area of the overlapping shaded area. In order to keep the connectivity when the nodes move and the uniformity of nodes distribution, so we suppose each part of shaded area as s_i and the objective function is:

$$F = \sum_{i=1}^{n} s_i$$

Taking the distribution should be uniform as much as possible into account; we define U as the measure of the uniformity of coverage:

$$U = \frac{1}{N}\sum_{I=1}^{N} U_i$$

$$U_i = (\frac{1}{k}\sum_{j=1}^{K}(D_{ij} - M_i)^2)^{1/2})$$

N is the total number of nodes; K_i is the number of neighbors of the ith nodes; D_{ij} is the distance between the ith nodes and the jth nodes; M_i is the average distance between the ith nodes and all the nodes which intersect within its scope

We still need to check the degree of redundancy of the function, so covering multiplicity represents the degree of redundancy of a certain covered area. If this area is within the extent of sensing coverage of K nodes, then its covering multiplicity is K. The specific mathematical expression is:

$$K_A = \sum_{i=1}^{n} k_i$$

$$k_i = \begin{cases} 1, A \subseteq A_i \\ 0, A_i \cap A \neq A \end{cases}$$

In the course of quadratic optimization, we should not only guarantee the condition of meeting connected set, that is, to obtain its shortest path when achieving a certain detection performance, greatly reducing the cost of detection, but also we should satisfy the requirement of the smallest overlapping area, evenly distributed and the minimum degree of redundancy as much as possible, thus ensuring that the wireless network formed by the repaired nodes can possess a longer working life, saving energy and increasing the efficiency.

CONCLUSION

When the natural disaster suddenly happens, it is of great necessity to have a monitoring system covering the whole areas formed by a considerable number of intelligent devices in order to instantly observe and monitor the condition of disaster area. Due to the limited ability of perception and coverage for each node, we should a new and effective coverage plan. Through setting up the probabilistic mathematical model, geometric mathematical model and redundant node model, this study make the complex problem simple which facilitates the deployment of new nodes and improves the efficiency of the node deployment. Taking various factors into consideration, the author establishes a new model which minimizes the cost of node deployment. Since the nodes will die again after repairing, we improve the model, making it an optimal repair guideline which facilitates the deployment of minimizing the cost of nodes and optimal repair.

ACKNOWLEGMENTS

This project is supported by Zhejiang provincial natural science foundation of China under grant LQ12F03014 and Y13F010063, Zhejiang provincial public service technology research and industrial project of China under grant 2012C21042 and a general project, Zhejiang provincial education de partment of China under grant Y201225827.

REFERENCES

Anastasi, G., M. Conti, E. Gregori, A. Passarella and L. Pelusi, 2006. An energy-aware multimedia streaming protocol for mobile users. J. Pervasive Comput. Commun., 1: 42-50.

Anastasi, G., M. Conti, E. Monaldi, A. Passarella, 2007. An adaptive data-transfer protocol for sensor networks with data mules. Proceedings of the International Symposium on a World of Wireless, Mobile and Multimedia Networks, June 18-21, 2007, Helsinki, Finland.

Baek, S.J. and G. de Veciana, 2005. Spatial energy balancing in large-scale wireless Multi-hop networks. Proceedings of the 24th Annual Joint Conference of the IEEE Computer and Communications Societies, March 13-17, 2005, Miami, FL., USA., pp: 126-137.

Johnson, D., D.A. Maltz and Y. Hu, 2004. The dynamic source routing protocol for mobile ad hoc networks (DSR). IETF Internet-Draft.

Foulds, L.R., 1984. Combinatorial Optimization for Undergraduates. Springer-Verlag, New York.

Garcia-Luna-Aceves, J.J. and S. Roy, 2005. On-demand loop-free routing with link vectors (OLIVE). J. Select. Areas Commun., 23: 533-546.

Srinivasan, V., C.F. Chiasserini, P.S. Nuggehalli and R.R. Rao, 2004. Optimal rate allocation for energy-efficient multipath routing in wireless Ad Hoc networks. IEEE Trans. Wireless Commun., 3: 891-899.

Busse, M., T. Haenselmann and W. Effelsberg, 2006. TECA: A topology and energy control algorithm for wireless sensor networks. Proceedings of the 9th ACM International Symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems, October 2-6, 2006, Torremolinos, Spain, pp: 317-321.

Wu, X. and B. Bhargava, 2005. AO2P: Ad hoc on-demand position-based private routing protocol. IEEE Trans. Mobile Comput., 4: 335-348.

Yin, S. and X. Lin, 2005. Multipath minimum energy routing in ad hoc network. Proceedings of the International Conference on Communications, May 16-20, 2005, Seoul, Korea, pp: 3182-3186.