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Optimization Algorithm for Efficient Coverage and Connectivity for Wireless Sensor Networks

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Abstract: Wireless sensor network an upcoming technology has its own application in various domains. The role of identifying different types of signals in a single network is being predominantly performed by heterogeneous networks. The essential parameters required for the upliftment of wireless sensor networks are effective connectivity, coverage, scalability and energy efficiency. The aim of the study is to maximize the coverage and scalability with minimized number of nodes. For this minimization of nodes, branch and bound approach is being mainly applied. Since, the nodes are to be minimized, the position where the nodes have to be located plays a crucial role. This problem can be solved by various optimization techniques. For the sake of identification of location of nodes for maximum coverage, Ant Colony Optimization (ACO) algorithm can be used. The ACO algorithm has the maximum probability of identifying the solution for this problem when compared to other algorithm techniques. Thus, the efficient coverage and connectivity can be achieved with minimum number of nodes by means of the proposed method.

Key words: Wireless sensor networks, coverage problem, connectivity, branch and bound technique, ant colony algorithm, connected covers, deployment of sensors

INTRODUCTION

Wireless Sensor Network (WSN) was built as a realizable platform because of its evolution in minimum power micro-electronics, wireless technologies and operating system. Prior WSN were influenced and treasure by the military uses such as monitoring activity on the battlefield (Akyildiz *et al*., 2002). Now it is being used in many civilian applications, habitat and circumstances monitoring. So, the wireless sensor network has turned to be the astonishing area in the field of research (Ray and Varshney, 2009). Wireless sensor networks are built of connected sensors and each sensor has the proficiency to gather, task and deposit the environmental data and communicate with others through inter-sensor wireless communication. The coverage problem is labeled here since sensors had restricted sensing ranges (Ilyas and Mahgoub, 2005). Any sensor network is supposed to achieve its coverage level in order to assure its quality of the service provided by the network field.

Coverage and connectivity: This section introduces the notion of the degree of coverage proposed by Ghosh and Das (2008) as follows. In more simple manner, the coverage in degree at any specific point in the sensing area could be mapped to the number of sensors with their sensing range covering that point. This has been stated that several unsimilar applications would need unsimilar or dissimilar degrees of coverage in the area of sensing based on the observations. For example, in the case of military surveillance application, it is necessary that a single site has to be monitored by several nodes simultaneously and so it requires a high degree of coverage. Suppose if the functionality of any one node fails, the other nodes will pursue their functionality irrespective of the failed one and the security of the site would be achieved without any controversies. While some might need only a low degree of coverage and it would be in the case of animal habitat monitoring and other environmental monitoring cases. But for some particular applications, the degree of coverage in a network can be forcibly configured in case it requires a

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framework. For example in intruder detection, a moderate degree of coverage is employed as far as no threat is realized or occurs in a confined region and in case of any misfortunes, the network will need to self-configure and grow their degree of coverage at specific regions as areas with a high degree of coverage would be more rebounding to node failures. Hence, the caliber of coverage varies across several applications and taken into account for the new grouping strategy development.

The concept of connectivity is as equal as coverage parameters in wireless sensor networks. In case, if a sensor network is designed as a graph by making the sensor nodes as vertices and by making a link in communication, if it exists into any two nodes as an edge. Thus, if the network connection is being made, the underlying graph is also said to be connected with consecutive edges and hence into any two nodes, there exists a one hop or many hop communication paths. The otion of degree of network connectivity can also be defined in the same manner as degree of coverage been defined. A sensor network is specified to have ‘n’ connectivity or be ‘n’-node connected (Jie Jia *et al*., 2010) if removal of any (n-1) nodes does not affect the latent communication graph connectivity. It provides formal definitions of ‘n’ connectivity and ‘n’ coverage from the graph theory approach. Single-node connectivity as if single degree of coverage (Li and Yu., 2007) is not enough for several sensor network applications because of the reason that even if any single node malfunctions, the entire network gets disconnected.

Robustness and throughput of a sensor network have to be taken into account as they have a direct relation with connectivity. Hence, the goal of a best sensor deployment strategy is to have a network connected all over the globe while most effective coverage at the same time. The deployment schedule would guarantee that maximum area in the sensing field is covered by sensors which are by means of optimization of coverage as required by the latent application. Once the network connection has been confirmed it is ensured that the sensed information is sent to other nodes and also to a centralized base station which can make treasured decisions in the application.

MATERIALS AND METHODS

The network life time is the basic criteria for checking a WSN. Network lifetime could be defined as the interval over which the network satisfies the application necessities and is the challenging issues in WSNs as maximum elements of WSNs are motorized by nonrenewable batteries and hence very difficult to lengthen the life time.

At the motive of extending the network lifetime, issue of pointing out the extreme number of connected covers in a diverse WSN is considered. ACO-MNCC an ACO-based approach stated by Lin *et al*. (2012) is used to solve the problem. The approach searches for the best results by always follow one more connected cover than the best-so-far solution. This approach increases the search capacity by framing explicit goal for the ants, avoiding excessive built of subsets. Pheromone and heuristic details are also regulated to increase the search process.

Use of the above technique in a construction of minimum number of nodes (Rajan *et al*,. 2013) by Branch and Bound together with the Steiner tree concepts improves both connectivity and coverage. In many standard methods for less usage of sensors for a larger area is attained by choosing ‘n’ nodes out of ‘m’ nodes through spanning tree concepts.

The proposed method is best for having entire coverage of the complete target sensing area by using the only less number of sensors and also maintains connectivity by the means of maximum number of connected covers. The results are optimistic that this method could reduce the sensor network nodes (Boukerche *et al*., 2007) with efficient connectivity.

Constraints considerations:

- The coverage constraint where the sensor needs to fully cover a target area T
- The collection constraint which needs the sinks to collect all the monitoring results acquired by the sensors in the same subset. Assume that the sensors cannot relay data
- The routing constraint which is required by the sinks to transmit the collected monitoring results to the destination for the formation of the network

Devloyment of the fewer sensors on grid points to package a connected wireless sensor network granted to fully cover critical square grids, called CRITICAL-SQUARE-GRID COVERAGE (Ke *et al*., 2007). The first step in deploying the wireless sensor networks is to resolve with respect to application specific performance criteria. If the sensors are fixed, where to deploy and implement them or if the sensors are mobile, how to plan the trajectory for mobile sensors. Subset of active sensors, alternate of all the sensors can carry out

Process ACO metaheuristic:

Planned activities
Build ants solutions
Upgrade pheromones
end-planned activities
end-process

Fig. 1: The pseudo-code for ACO metaheuristic

a task while the rest of the redundant sensors can go into the sleep mode for energy safety (Chamam and Pierre 2009). The coverage problems intend to seek such a method in order to increase the network lifetime while satisfying the coverage demands (Fig. 1).

Branch and bound algorithm:

- Stated the input graph C's is the no. of terminals in C
- Find the starting maximum and minimum bound values
- IE = Ω; IE denotes the included edge
- For n = 1:s
- Calculate the contrast between lightest and upcoming lightest edge is maximum and select the node with lightest edge to branch on. Add that edge to IE
- If Minimum bound greater than equal to Upper bound
- Stop furthermore reduction

else go to step 4 end. The algorithm begins with the starting graph and slowly making more and more decisions, lastly ends up with one specific tree. Shrinkage means removing the edge and exchange two nodes connected by the edge by a single node.

Ant colony algorithm: An ACO algorithm can be visualized as the interaction of three procedures:

- Build ants solutions
- Upgrade pheromones
- Daemon operation (Optional)

In Fig. 1 the ACO, metaheuristic is described in pseudo-code (Dorigo and Stutzle, 2004). The main process of the ACO metaheuristic manages the planning of ACO algorithms via the Planned Activities construct:

- Pheromone upgrading
- Management of the ants function

The flow chart for the problem of finding connected covers is as shown in Fig. 2.

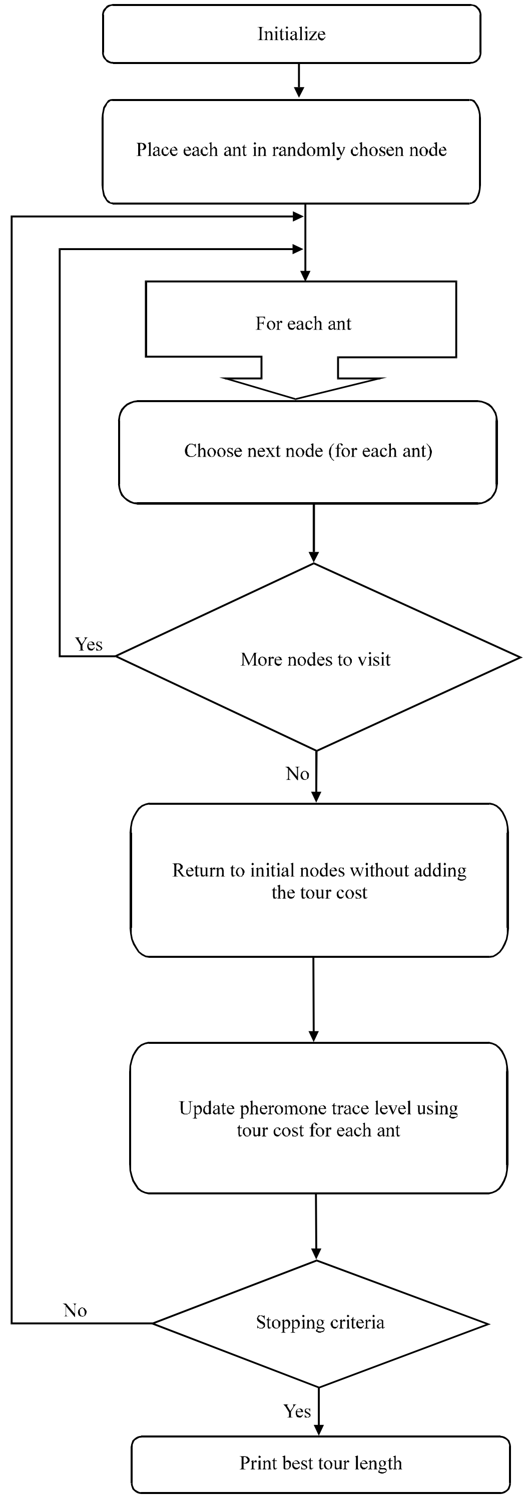

Fig. 2: Flow chart for the problem of finding connected covers in the network

Probabilistic transition function: In the build of solutions, pheromone value between every state is upgraded from the initial value. This is based on the set of best-so-far solution. In next iterations the solution is chosen based on the probability value. The probability of choosing the solution set can be equated as shown in Eq. 2:

$$u^{i}_{ab}(j) = \begin{cases} \dfrac{[S_{ab}(j)]^{x}[T_{ab}]^{y}}{\sum_{i \in permitted_i} [S_{ai}(j)]^{x}[T_{ai}]^{y}} & \text{if } b \in permitted_i \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Updating rule for pheromone: After building of best-so-far solution, the value of pheromone value is upgraded based on evaporation rate and previous pheromone value. The formula for upgrading the pheromone level at each iteration is shown in Eq. 2.

$$S(x,y) \leftarrow (1-q)\cdot S(x,y) + q\cdot S_0 \quad (2)$$

In the Eq. 2 S(x,y) mention the pheromone level (S) between the states ‘x’ and ‘y’. It is upgraded with evaporation rate (q) along with early pheromone value (S_0), at every iteration.

RESULTS AND DISCUSSION

In the building of the sensor network, Branch and Bound along with Steiner tree concepts achieve full coverage of the entire target sensing area using less number of sensors. The proposed approach has been simulated in matlab with creation of graph model for the solution obtained in Branch and Bound technique. Figure 3 shows the terminal nodes and its edge weight (Chartrand and Zhang, 2006) of a network taken for deployment of the network grid model shown in Fig. 4.

In the network graph model with less number of nodes, connected covers were detected using Ant Colony Optimization technique. Different set of networks analyzed for connected cover solution with minimum distance. The optimal solution obtained for each iteration among every ant solution. For smaller size network, the optimal solution is detected at very earlier iterations. The Pheromone level at successive iterations at every edge is as shown below.

The early pheromone level between every node is initiated with value ‘1’. This is figured out in the network graph model as shown in Fig. 5. Similarly, at each iteration the pheromone level upgrade between nodes at 1st, 5th, 15th iteration is shown in Fig. 6-9, respectively.

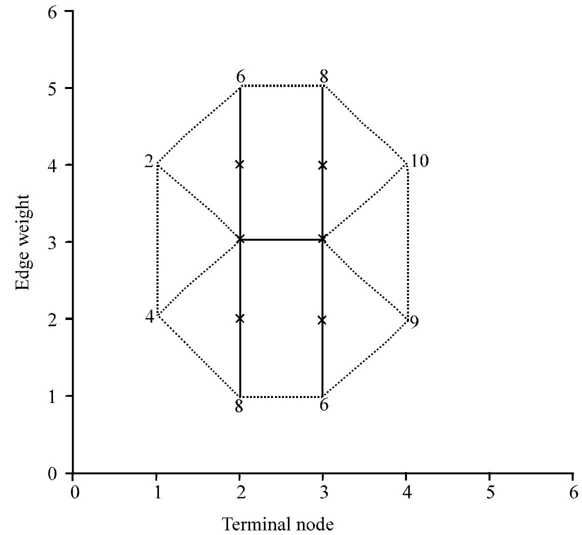

Fig. 3: Input network graph model

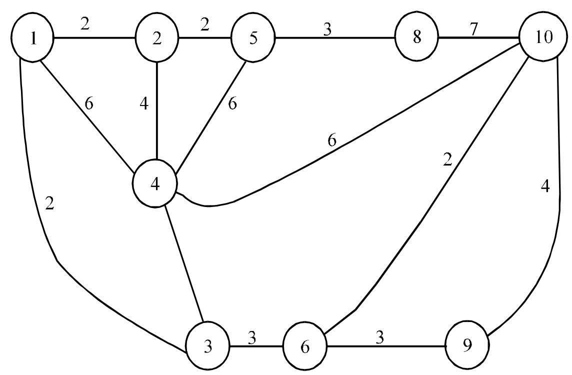

Fig. 4: Graph model with reduced number of nodes

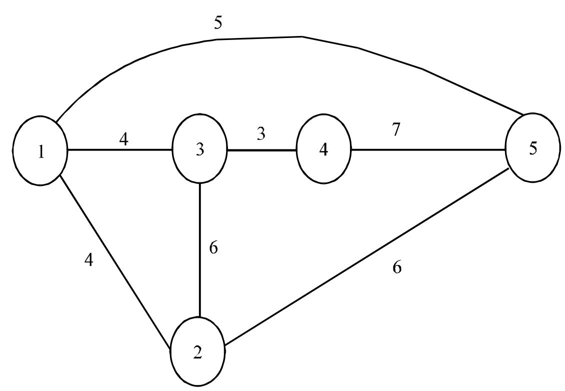

Fig. 5: Pheromone level at Initial stage

In the larger degree of iteration the higher value of pheromone level indicates the connected cover in the network with shorter distance. For larger networks, the optimal tour value is obtained at later iterations. In Fig. 10

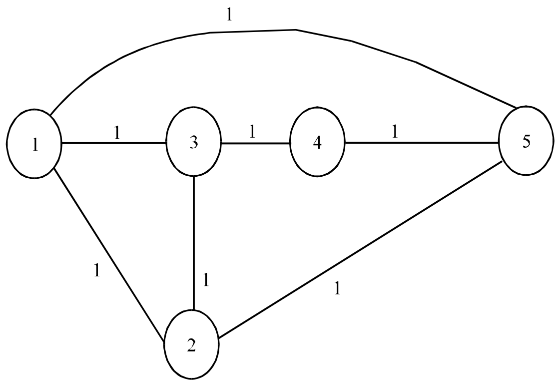

Fig. 6: Pheromone level at initial stage

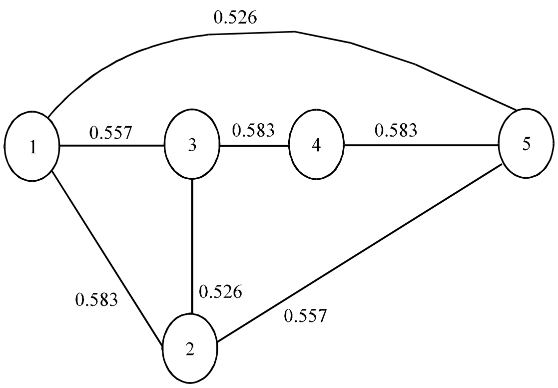

Fig. 7: Pheromone level at 5th iteration

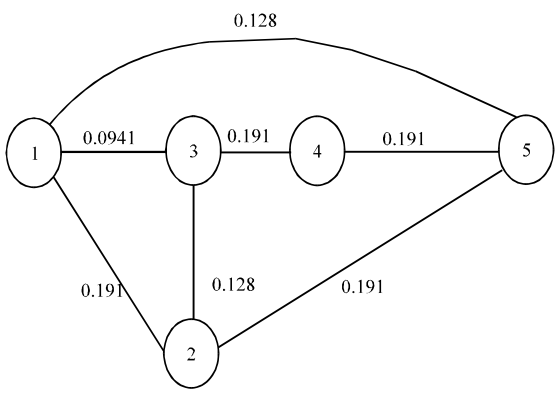

Fig. 8: Pheromone level at 14th iteration

the network with forty nodes, the solution is obtained at thirtie th iteration. This is obtained based on the best-so-far solution and upgrading the pheromone level of every edge of the network.

Test cases: Wireless sensor networks with different scales are being employed in the experiments. In WSNs

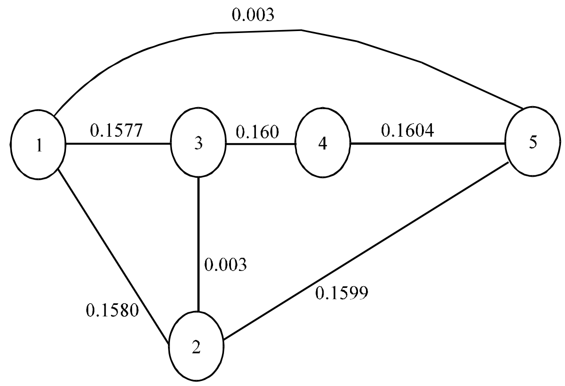

Fig. 9: Iterations vs. optimal tours

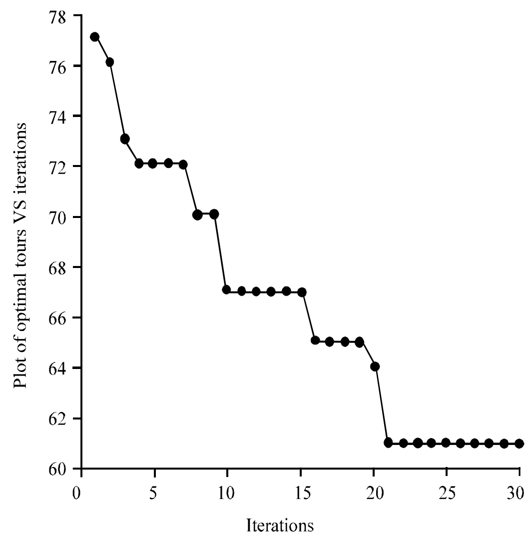

Fig. 10: Iterations vs. optimal tours

Table 1: Test cases

Test case No.	No. of nodes before branch and bound	After branch and bound	No. of connected covers	No. of iteration	Best tour length	Elapsed time (sec)
1	5	4	2	30	20	3.356036
2	10	6	4	30	37	3.989417
3	15	9	5	30	32	6.532804
4	20	13	2	30	63	8.124703
5	25	16	7	30	51	14.519
6	30	25	10	30	69	26.059221

are created by randomly grouping sensor in a 12×12 rectangle. Table 1 tabulates the number of nodes in before and after branch and bound technique, number of connected covers and iterations, Best tour length and CPU elapsed time for the technique to obtain the results. Figure 11 shows the output of before and after Branch and Bound Technique (BBT), number of Connected Covers (CC), Best Tour Length (BTL) and CPU Elapsed Time in Seconds (ETS).

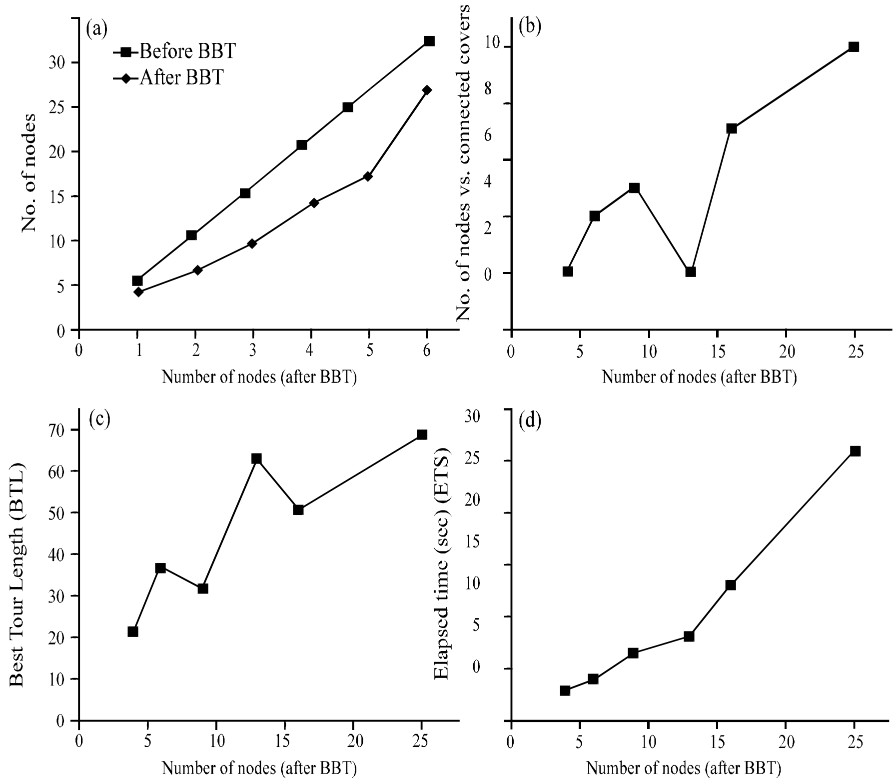

Fig. 11: Curves of before and after BBT, No. of CC, BTL and CPU-ETS: a) Before and after Bound Technique (BBT); b) No. Nodes vs. Connected covers; c) Best Tour Length (BTL) and d) Elapsed time (sec)

CONCLUSION

Deployment of the least sensor nodes on grid points to build a connected wireless sensor network has the ability to fully cover critical square grids while using Steiner tree concepts. Branch and bound process is better for having full coverage of the whole target sensing area by using only the less number of sensor nodes. With Ant colony approach as the number of connected covers increases, the lifetime of the network extends.

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