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A Literary Study of Coverage and Connectivity in Wireless Sensor Networks for Optimal Performance

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Abstract— **Wireless sensor networks is one of the upcoming and developing technologies in the field of wireless communication. The energy efficiency of the sensor nodes to prolong network lifetime is highly essential when we look forward for actual development of any real time application based on sensor networks. Since physically accessing the nodes in the remote areas of deployment for their maintenance is difficult, the optimum power consumption with long life of the operating nodes is very important. The energy efficiency is related to data aggregation, coverage and connectivity in sensor networks. The wider option for increasing the life of an individual node and enhance the network existence for long time is optimization of sensing coverage, better connectivity. This paper gives a detailed literature review of various traits, problems and their solutions for coverage and connectivity in wireless sensor networks**

Index Terms— **Wireless sensor networks, Energy efficiency, Coverage & Connectivity.**

I. Introduction

Wireless sensor networks form extreme form of ad-hoc networks. In this technology, a large number of sensors are spatially laid down over a large area in order of several acres. These sensors are autonomously functioning and their purpose is mainly to sense the parameters like temperature, pressure, sound and monitor the environmental conditions. These nodes operate in complete co-operation with each other and transmit the data to the main location or the network. A complete electronic design of a wireless sensor network in terms of hardware is called as a mote. A mote comprises of various components like sensors, processors, mobilizing unit, memory chip and a transceiver or a RF module for the wireless transmission of signals. The frequency of operation of wireless sensor networks includes 315 MHz, 433 MHz, 868 MHz (Europe), 915 MHz (North America), and the 2.45-GHz Industrial-Scientific-Medical (ISM) band. The 2.45 GHz ISM band is more flexible as plenty of commercial RF devices are available in this band. The main issue of using this frequency band is the interference from the other applications which can be minimized by the use of frequency agile techniques or spread spectrum technology. The low frequency of operation (70 MHz or below) may provide better solutions for sensor network applications. The main areas of applications of sensor network being environmental observation, military surveillance and health care monitoring systems. The important functions include sensing the data, transmission of data, routing the data and finally sending it to base station or gathering data and then sending it to base station in case of cluster based hierarchy or LEACH protocol and its different versions. In all these steps effective utilization of power with concern that all the area under the coverage of the sensor nodes is being effectively monitored. Since the nodes cannot be physically accessed in the hilly areas or remote places, the actual replacement of nodes or repairing them is a difficult task, also cost of design and implementation of motes is very high due to which there is very less development in the real time applications of sensor networks. However, the energy efficient performance in all aspects is a major requirement in sensor networks.

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II. COVERAGE IN WIRELESS SENSOR NETWORKS

The one of the most fundamental researches in the wireless sensor networks is coverage. The sensing function of the network can be qualitatively assessed in terms of coverage. The additional advantageous feature associated with coverage formulation is that it attempts to detect weak points in the field and propose a suggestion of how the nodes can be deployed and reconfigured in future. The two basic traits taken into account for coverage analysis are performance assessment of coverage when the deployment of sensor nodes in the field is done and when the existing coverage technique becomes incapable of satisfying the requirement of desired application. Some algorithms target the coverage issues in sensor networks to characterize pure coverage while few integrate other considerations supporting the optimal utility of network resources for a specific application. The difficult challenge in is development of a coverage scheme with improved connectivity for enhancement of network lifetime.

The paper presents a complete literature survey and a thorough study of coverage and connectivity in wireless sensor networks.

A. Coverage Deployment Strategies

The different types of coverage [1] in sensor networks are point coverage, area coverage and path coverage. The area coverage is the type of coverage where a particular region i.e. area is monitored. The point coverage is the type of coverage in which a set of points i.e. targets is specifically covered. The path coverage is based on minimization or maximization of likelihood of penetration through region that is not detected.

The other way of broader classification of coverage is as listed below:

1. Static Coverage
2. Dynamic Coverage

The static coverage is the type of coverage in which the region of coverage is static i.e. fixed. In static coverage, effective coverage area, k-coverage and path coverage will be discussed. A static network deployment according to a specific shape can lead to deterministic coverage in sensor networks. In k-coverage, k represents the number of sensor nodes that essentially keep watch on each of the single point. Usually k=1 and the value of k greater than one will add an ambiguity to the coverage algorithm. The path coverage is based on the deployment of nodes to sense a particular route or path and reporting the attempts made by intruders to move across it. The dynamic coverage in sensor networks [1] is based on virtual force, graph based approach and repairing of coverage holes. The VFA can be used for coverage enhancement after the sensor nodes are placed randomly after the initial stage. An interesting data structure [1] in computational geometry is Voronoi diagram. This type of diagram mathematically enables the separation of plane into small regions. The separation is governed by distance of points in a specific subset of the same plane. The Voronoi based algorithms can be used for the coverage-hole recovery in wireless sensor networks. The sensor nodes will be laid down randomly in an area with availability of any spare nodes. In case if a coverage hole is detected, the network needs to undergo augmentation with spare nodes.

B. Node Deployment Techniques

The various methods for deployment of sensor nodes [2] are as listed below:

1. Uniform random
2. Square grid
3. Hexagon Tiling

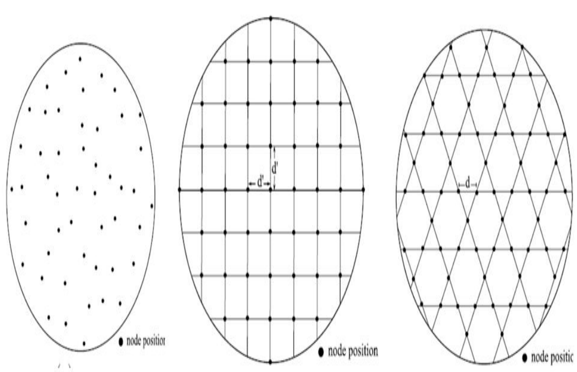

Fig.1: Node deployment techniques [2].

In the first method the nodes are randomly placed over a given area. This type of technique is used for deployment over very huge areas for the applications like military surveillance, earthquake monitoring, seismic activity monitoring etc. The nodes are randomly thrown over the area through air vehicles like helicopter following some probabilistic distribution. The nodes will spread randomly, somewhere large number of nodes and at some places very less number of nodes will fall. Hence, use of sleep scheduling algorithms, efficient MAC protocols or advanced mathematical models to ensure that the entire area is fully covered with no wastage of power and long lived sensor nodes. In the second method, the region to be monitored is divided into identical square shaped areas and the sensor node is placed at the vertex of each of the square. In the third method, the region is divided into identical hexagons where a sensor node is placed at the vertex of each of the hexagon. These techniques are suitable in some applications like irrigation systems, healthcare systems where a disciplined placement of nodes in a predefined geometry. The coverage problem and energy efficiency is not very crucial in these two cases. However in the first case monitoring the complete area is certainly a very challenging task.

C. Coverage Problems in Sensor Networks

The coverage problems in the wireless sensor networks [3] can be formulated in the following three types.

1. Art Gallery Problem (AGP)
2. Circle Covering Problem (CCP)
3. Robotic Systems Coverage (RSC)

In case of art gallery, if the interior part of art gallery is represented by a polygon then finding least no of guards required to monitor the interior of the gallery is roughly the art gallery problem which is more or less similar to the random deployment of the sensor nodes in the sensor networks. The AGP problem can be solved in 2D as well as 3D. The 3D solution is based on NP-hard.

If the coverage region of a sensor node is considered to be a circle, then reducing the radial distance with the requirement the complete area is covered within the given plane is required. The CCP refers to the arrangement of the identical circles to fully cover the plane. No universal method to overcome this problem is available.

In case of RSC, the coverage can be of three type blanket, barrier and sweep type. In the first type, the goal is to enhance the spatial arrangement of sensors so the total area being monitored is maximized. The second type targets to reduce the penetration probability in statically arranged nodes. The third type resembles a moving a barrier.

D. Multiple Random Nodes Covering Same Area

The problem with multiple sensor nodes covering the same area is as explained below.

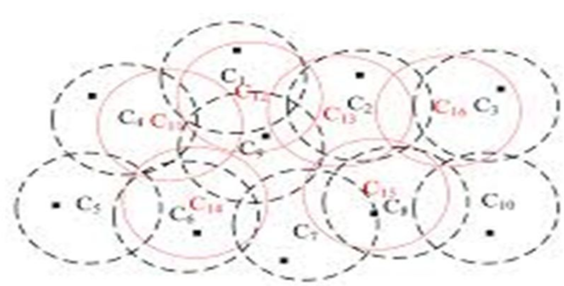

Fig.2: Multiple random nodes covering same area.

When multiple random nodes are deployed in the same area, there is the overlapping of the sensing coverage of the neighboring nodes because of which when one node can do a particular task in the given area, two nodes remain ON and do the same task which is an inefficient coverage and wastage of power.

III. COVERAGE SCHEMES IN WIRELESS SENSOR NETWORKS

There are various protocols for effective coverage in sensor networks. The different schemes for wireless sensor networks, the approach followed by them and their limitations is explained below:

A. Coverage Configuration Protocol (CCP)

Approach: This protocol is based on verification of the intersection points within the sensing area are k-covered in order to make sure k-coverage is achieved.

Limitation: When the transmission range exceeds twice the sensing range, there is possibly no connectivity in the network.

B. Adaptive Self-configuring Sensor Network Topologies (ASCENT)

Approach: In this protocol, the topology will be automatically established that makes the redundant sensors undergo sleep for enhancement of coverage.

Limitation: The main drawback is that the working nodes get back to sleep which may affect the coverage.

C. Optimal Geographical Density Control (OGDC)

Approach: This protocol is based on decentralization of the sensor nodes and establishing the density control.

Limitation: The accurate information of the location of the node and requirement time synchronization forms a major drawback of this protocol.

D. k-Neighbors Coverage Constrained Strategy (KCCS)

Approach: Based on virtual forces, the pairing of the nodes will be done and then the nodes will interact with each other.

Limitation: This protocol assumes that each of the nodes in the sensor network environment has the capability to measure exact range and detect the barrier in the neighboring nodes.

E. Random Independent Scheduling(RIS)

Approach: The aim of this protocol is to achieve k-coverage while the nodes being allowed to sleep for maximum time.

Limitation: The unexpected node failure occur which cause destruction of sensors till they completely run out of energy.

F. Light weight Dependent Aware Scheduling(LDAS)

Approach: The redundant nodes in the sensor field are analyzed. The exceeding the number of working nodes results into threshold node turns off and tickets are sent to it.

Limitation: The tight under-bound of likelihood of obtaining complete redundancy and the analysis of redundant areas is difficult.

IV. INTERDEPENDENCE OF COVERAGE & CONNECTIVITY

Connectivity in wireless sensor networks imply that all the pair of nodes i.e. all the nodes in the deployed area are connected to each other and ultimately the base station or the sink node. The various fundamental principles [4] used for communication in wireless sensor networks are stated below:

1. Conventional hopping
2. Co-operatively sending the data through wave propagation.
3. Gathering the co-operatively sent data.
4. Hybridized transmission combining 1 & 2.

The second method can be used to achieve appreciable improvement in the connectivity of sensor nodes deployed in a field. If the network is either partitioned or comprises of a sparse setting, then the traditional methods fail to maintain the connectivity of sensor nodes in the network environment. If the groups of sensor nodes in the field are found to be not connected, then this method can be used.

The effective transmission of data in sensor network environment is determined by connectivity. The requirement of connectivity is that position of ON node or active node which lies in the communication range of multiple active nodes so that all the connected units form a common backhaul. The effective coverage demands all the locations or the points in the sensor field should be under the governance of a at least a single node. The configured nodes consist of connected networks to send information collected back to centers. The reason to find interdependence coverage and connectivity is to use minimum no of sensor nodes to optimize coverage and maintain the connectivity throughout the network.

The three important theorems to study the interdependence of coverage and connectivity for better network performance are stated below:

1st Theorem: If the region is k-covered, there exists the possibility of lost connectivity of a boundary node from the others nodes in the communication graph.

2nd Theorem: The k-covered nodes will be k-connected under the condition communication radius is greater than or equal to twice the sensing radius.

3rd Theorem: The interior connectivity of 2K can be obtained for k-covered sensors if $Rc \geq Rs$.

The optimal performance can be achieved in wireless sensor networks by deploying various algorithms to achieve effective coverage and improved connectivity in order to prolong the network lifetime.

V. SUMMARY

The main bottlenecks in the coverage of sensor networks are listed below:

1. Deployment techniques for nodes used to cover the area.
2. Sleep scheduling algorithms used to increase the sleep time of the nodes.
3. Controllable radial distance over which effective coverage can be achieved.

The solutions to these problems depend on the sensing model, deployment strategy, type of coverage and knowledge of location of the node. The various approaches to deal with the problems mainly include computational geometry, VFA's, mobility, sleeping of the nodes, disjoint sets etc. The various solutions based on it have been proposed.

The research challenges and problems related to coverage and connectivity of sensor are:

1. The optimal techniques for deployment of sensor nodes.
2. Introducing novel algorithms with innovation for coverage control in real time scenarios.
3. Improvised sensing models with effective design for better coverage.
4. The three dimensional coverage based on NP-hard is a developing concept in this area.

CONCLUSION

The optimal performance in a very important consideration to develop any real time application based on wireless sensor networks. The energy efficiency and optimum power consumption of the nodes can prolong the network lifetime The various methods for deployment of sensor nodes, coverage problems in the sensor networks were discussed. In case of applications like seismic activity monitoring, earthquake monitoring where the nodes are randomly deployed over a very large area, the effective coverage i.e. energy efficient coverage is a stringent requirement and connectivity of the sensor nodes is a very crucial issue. Hence development of new algorithms with advanced stochastic modeling is needed. The coverage and connectivity are two sides of the same coin i.e. both are equally important to develop successfully a network. The recent study in the area of sensor networks is improvisation and development of various algorithms for better coverage and improved connectivity.

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