



## Analysis of Strategies of Placing Nodes in Wireless Sensor Networks

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**Abstract**— Two critical design issues of almost every wireless sensor network, area coverage and extended lifetime of network. Appropriate node placement has proved to be a very effective approach for optimizing the desired design goals. The node placement strategies can be categorized into dynamic and static depending on whether the optimization is performed while the network is operational or at the time of deployment, respectively. In this paper we will discuss and classify the already develop techniques based on the role that a node can play in the wireless sensor network. The primary objectives of placing nodes in WSNs are also discussed with some of the already published work.

**Keywords**— Area Coverage, Network Lifetime, Node Placement, Relay Nodes, Wireless Sensor Networks

### I. INTRODUCTION

A wireless sensor network consists of sensor nodes deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events, and so on [1]. Each sensor node in a sensor network can sense only within its vicinity. The data generated by each sensor is required to be sent to a destination, known as base station or sink, from where the user can access the data, usually through the Internet, to extract some useful information. Recent years have witnessed an increased interest in the use of wireless sensor networks (WSNs) in numerous applications such as forest monitoring, disaster management, space exploration, factory automation, secure installation, border protection, and battlefield surveillance [1].

In most of the applications, sensor networks are deployed to operate autonomously in unattended manner i.e. in remote and hostile locations. Therefore, it is not feasible to replace the power-source of sensor nodes, which are generally the batteries with limited energy budget. A sensor stops working when it drains out of energy. If many sensors got depleted of their energy source, the whole network may get structurally damaged. Hence, prolonging the network lifetime becomes the most critical issue of such networks.

In addition to energy conservation, there are few more challenges as well, such as coverage, fault-tolerance, self-configurability, scalability, Quality of Service and connectivity etc. Negligence of these significant issues could sometimes results into severely poor performance or may even lead to inoperability of the whole network. These features must be incorporated simultaneously into a wireless sensor network to achieve an effective functioning of the network.

### II. NODE PLACEMENT TECHNIQUES IN WSNs

Position of nodes in a wireless sensor network affects certain network performance metrics such as energy consumption, delay and throughput. For example, energy consumption may get increased due to weakened communication links if the distance between nodes gets larger. Optimal node placement is a very challenging problem that has been proven to be NP-Hard for most of the formulations of sensor deployment [4][5]. To tackle such complexity, several heuristics have been proposed to find sub-optimal solutions [4][6][7]. However, these optimization strategies are based on the analysis of fixed topologies. Therefore, such approaches can be classified as static Fig. 1.

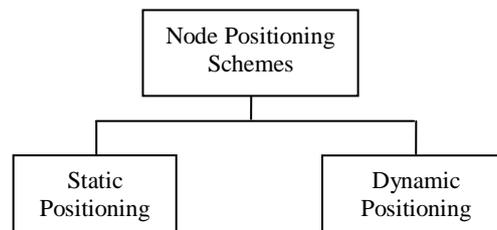


Fig. 1. Types of Nodes' Positioning Schemes

On the other hand, some schemes have advocated dynamic adjustment of nodes' location since the optimality of the initial positions may become void during the operation of the network depending on the network state and various external factors [8][9]. Since, the available network resources may vary over time such as new nodes could join the network, or the existing ones may run out of their energy.

**A. Static Positioning of Nodes**

Sensors can generally be placed either deterministically or randomly. The selection of the deployment strategy depends on the type of sensors, application and the environment that the sensors will operate in. As mentioned earlier, the position of nodes have a considerable effect on the performance metrics of a wireless sensor network. Static node placement technique comes into play before network start-up. This approach usually choose the particular nodes' positions on metrics that are either independent of the network state or assume a constant pattern of the network operation that remain unchanged throughout the network's lifetime. Examples of such static metrics are area coverage and inter-node distance, etc. Static network operation models generally assume periodic data collection over predefined routes.

**B. Dynamic Positioning of Nodes**

Some of the protocols use static positioning approach, initially compute the optimal location for the nodes and do not alter their location, once they were deployed. The optimization strategies applied for static positioning assess the quality of candidate positions based on performance metrics like the data rate, sensing range, path length in terms of the number of hops from a sensor node to the base-station, etc. In case of variation in available network resources, misbalance of load may occur among the nodes, resulting into bottlenecks. Therefore, in order to enhance the performance of the network, it is necessary to reposition the nodes while the network is operational. This dynamic relocation technique is often utilized in target tracking application where the target is mobile. While the network is in operational mode, relocating its nodes is very difficult. Dynamic relocation is done while monitoring the network state in response to a network-based or environment-based stimulus. It thus requires continual analysis of performance as well as occurrence of events in the vicinity of the node.

**III. ROLE-BASED PLACEMENT STRATEGIES**

For establishing an efficient network topology, one of the most effective methods is positioning of relay nodes. Alternative schemes of topology management, such as [10][11], assume redundant deployment of nodes and selectively engage sensors in order to enhance the network lifetime. Relay node placement problem can be solved various forms; each of them has its own advantages and disadvantages because of communication ranges of relay as well as sensor nodes, allowing a sensor to behave as a hop on the data path, assuming flat or tiered network architecture.

The capability of relay nodes may vary widely. For flat network architectures, the relay node (RN) can be considered as just an ordinary sensor node. However, in two-tiered network architecture, relay nodes usually act as a gateway for one or multiple sensors to the other nodes in the network Fig. 3. The transmission range of sensors is often assumed smaller than relay nodes. The relay node placement problem becomes harder, when relay nodes do not directly transmit to the base-station, since it involves inter-RN networking issues. The various roles played by a node in WSNs are as shown in Fig. 2.

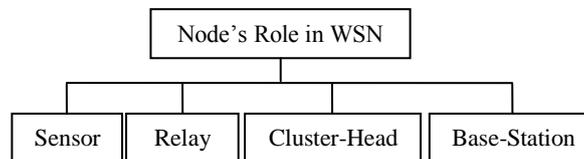


Fig. 2. Roles Played by a Node in a WSN

In [12] the author has described the work on relay nodes' randomized deployment, whereas in [13][14][15] the focus is on deterministic placement of relay nodes. In [13] the authors have considered the placement of relay nodes that can directly reach the base-station. Given a deployment of sensor nodes (SNs), the problem is to find the minimum number of relay nodes (RNs) and where they can be placed in order to meet the constraints of network lifetime and connectivity. The problem is represented as equivalent of finding the minimum set covering, which is an NP-Hard problem. Thus, a recursive algorithm is proposed to provide a suboptimal solution. The algorithm pursues a divide-and-conquer strategy and is applied locally. Sensors collectively found their transmission ranges' intersection. At intersections of the largest number of sensors, relay nodes are placed. So that optimum number of sensors can be served by a relay node. This work has been further extended in [14][15] to address the problem of deploying a second-tier of relay nodes, so that the traffic remain balanced as well as least number of additional relay nodes could be used.

**IV. OBJECTIVES OF NODE PLACEMENT**

Most of the node placement techniques have focused on increasing the area coverage, obtaining strong network connectivity, extending the network lifetime and improving the data fidelity. Few more benefits of placing nodes are observed such as tolerance of node failure and load balancing. The primary objectives of placing nodes in WSNs are shown in Fig. 3.

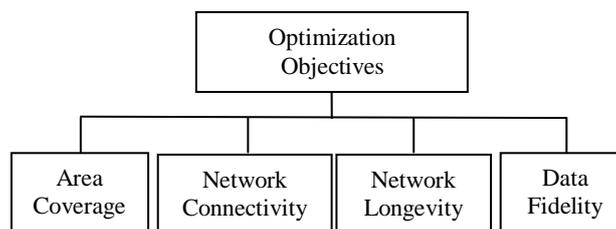


Fig. 3. Primary Objectives for Placing Nodes in WSNs

Most of the work strives to maximize the design objectives using the least amount of resources, e.g., number of nodes. It is obvious that achieving the design objectives is not feasible through random node distribution. However, deterministic placement could theoretically satisfy all objectives of placing node; the need for minimizing the required network resources keeps the problem very hard.

*A. Area Coverage*

Most of the research in this field had been done on the performance improvement of sensor network with an assumption that the networks have already been deployed. The study on the node placement and coverage problems deals with efficient deployment of sensor nodes within the networking field. A sensor node monitors only a small area from its vicinity. Hence, data cannot be obtained from a region, which is not covered by at least one sensor node. This means that the coverage of sensor network must be taken into consideration while placement of sensor nodes. Coverage is an important field in sensor networks and it has been discussed in many papers, including [2][3].

On the basis of network model, coverage can be measured in more than one way. A network model specifies the area covered by a certain sensor at a certain location. A network model can be either deterministic or probabilistic. A deterministic network model specifies the area, which is covered by a sensor node. Whereas, a probabilistic network model determines the probability, that a phenomenon will be detected at a given location. In order to ensure coverage, sensor nodes could be deterministically placed in the environment. However, in most of the applications sensor nodes are randomly deployed. Thus, it is difficult to yield uniform node density while maintaining strongly connected network topology. Therefore, controlled placement strategy can only be applied to the selected subset of deployed nodes with the aim of structuring the network topology, in order to achieve the desired application requirements.

*B. Network Connectivity*

In some of the early work, network connectivity has been regarded a non-issue based on the assumption that the sensing range of a node is much shorter than its transmission range. A theory states that good coverage will result into a strongly connected network when transmission range is a multiple of sensing range. However, if the communication range is limited, e.g., Transmission range is equals to Sensing range, connectivity becomes an issue unless substantial redundancy in coverage is provided. Kar and Banerjee have considered sensor placement for complete coverage and connectivity [16].

*C. Network Longevity*

Prolonging network lifetime has been the primary objective for most of the published communication protocols for WSNs. The positions of nodes significantly impact the network lifetime. For example, variations in node density throughout the area can eventually lead to unbalanced traffic load and cause bottlenecks [17]. In addition, a uniform node distribution may lead to depletion of energy of nodes that are close to the base-station at a higher rate than other nodes and thus shorten the network lifetime [18]. Some of the published work, such as [12] has focused on extending the network lifetime rather than area coverage. Here, the assumption is that there are an adequate number of nodes or the sensing range is large enough such that no holes in coverage may result.

The sensor deployment problem for maximum lifetime with coverage constraints has been discussed in [19]. The authors assume a network operation model in which data report is send to the base-station periodically by every sensor. For the longest time the network is required to cover a number of points of interest. For measuring the sensor's lifetime the average energy consumption per data collection round is used as a metric.

*D. Data Fidelity*

One of the important design goals of WSNs is to ensure the credibility of the gathered data. A collective assessment of the detected phenomena is provided by a sensor network through fusion of the readings of multiple independent (and sometimes heterogeneous) sensors. Increasing the number of sensors deployed in a particular region will definitely enhance the accuracy of the fused data. However, redundancy in coverage would require an increased node density, which can be undesirable due to cost and other constraints. Zhang and Wicker have looked at the sensor placement problem from a data fusion point of view [20]. They note that there is always an estimation distortion associated with a sensor reading which is usually countered by getting many samples. The approach is to partition the deployment area into small cells, then determine the optimal sampling rate per cell for minimal distortion. Assuming that all sensors have the same sampling rate, the number of sensors per cell is determined. The problem is transformed from the space to the time domain. Similar to [20], Ganesan et al. have studied sensor placement in order to meet some application quality goals [21]. The problem considered is to find node positions so that the fused data at the base-station meets some desired level of fidelity. The studied papers are tabulated in Table.1.

Table 1: A comparative representation of various node placement strategies

Paper	Application	Deployment	Node Type	Primary Objective	Secondary Objective
[4]	Generic	Deterministic	Data Collector	Network Lifetime	-
[5]	Biomedical	Deterministic	Relay	Network Lifetime	Min. relay count
[6]	Generic	Deterministic	Data Collector	Network Lifetime	-
[7]	Surveillance	Deterministic	Sensor	Coverage	Min. sensor count
[12]	Outdoor	Random	Relay	Network Lifetime	-

[13]	Indoor or non-harsh outdoor	Deterministic	Relay	Min. relay count	-
[14]	Indoor or non-harsh outdoor	Deterministic	Relay	Network Lifetime	Min. relay count
[15]	Indoor or non-harsh outdoor	Deterministic	Relay	Network Lifetime	Min. relay count
[16]	Outdoor	Deterministic	Sensor	Coverage & connectivity	Min. sensor count
[17]	Outdoor	Random	Relay	Network Lifetime	-
[19]	Surveillance	Controlled (nodes move)	Sensor	Network Lifetime	-
[20]	Outdoor	Random	Sensor	Data fidelity	-
[21]	Generic	Deterministic	Sensor	Data fidelity	Minimal energy consumption in communication

## V. CONCLUSION

Based on the above discussion and analysis done in the Table.1, it can be concluded that when there is need to place the nodes deterministically in this case, static approach is recommended. Static strategy will not work when random distribution of nodes is the only option. The use of mobile nodes would not be practical because of its higher cost and overhead. It is recommended to use mix approaches which, is practical solution. In WSNs, node may act in variety of ways. A node can behave as an ordinary sensing node, relay node, cluster-head or it can work as a base-station i.e. sink node. Network efficiency can be improved by placing relay nodes (RNs) strategically. The primary objectives of almost every node placement technique are to ensure the coverage area, increased network lifetime and adequate data fidelity.

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