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Abstract—There are various applications of Wireless Sensor Networks (WSNs) including industrial, environmental, military, health applications etc. Gathering information about a given condition of environment in a given zone is the main task of these networks. The sensors are being deployed manually or randomly in the area to be monitored. Sensors are very small in size and having different constraints like low energy, low communication range and low storage. The deployment strategies for WSN must be able to cope with obstacles and be energy efficient in order to increase the network lifetime. The deployment process is very much important in WSNs because coverage and connectivity is totally dependent on this. Here in this paper we present a review of coverage and connectivity issues and the impact of deployment on these factors. The paper presents the analysis of deployment issues and the factors influencing the deployment of WSNs. In conclusion hence paper gives current trends and open issues in this area.

Key words: Coverage, Deployment, Connectivity, Sensor Node, Wireless Sensors, WSN, Deployment Algorithm

I. INTRODUCTION

In a very short time sensors have become very first choice for gathering information from the surroundings. This is because sensors are very small in size and can be deployed anywhere where even human can’t reach. With the emergence of micro-electromechanical devices, several billion electronic devices are able to be connect to one another via the Internet. Wireless sensor networks can be able to work from machine-to-machine (M2M) without any intervention of human being. The sensors are able to work up to long time without any interference of human beings. There is a wireless communication between each node of the network and such communication is called as Machine-to-Machine (M2M) communication. These new technologies centered on wireless communications are able to operate autonomously and configure themselves in the network without any intervention of human beings. For example the random deployment of WSN in the monitoring area can be very useful for gathering data and maintaining the worksite for quality assurance. Now as the sensor nodes are battery operated and there is no external source of energy provided, the placement of nodes should be in such a way that it will increase the network lifetime. Also the environment in which the sensor network has been established is unstable in nature. So there should be a mechanism that the wireless sensor deployment should consider all the issues like coverage and connectivity in the network and monitored area. The wireless sensor network should be able to work in an unfriendly environment and be able to communicate the gathered data towards the base station. Some challenges are need to be considered while designing a deployment strategy for wireless sensor network, like (1) communication between nodes and the base station, (2) handling of the large amount of data with less storage, and (3) coverage of the monitoring area as desired by the application.

The sensor nodes are self-configurable and can arrange themselves in the form of a network when deployed in remote areas. This is the main focus of this review paper. While we design a deployment algorithm we can face many coverage and connectivity problems. The coverage can be of many types depending on the application like barrier coverage, point of interest coverage and full area coverage. There can also be a partial coverage depending on the application of WSN. If the coverage is full the point of interest can be covered fully by a single sensor node called as simple coverage or by several nodes known as the multiple coverage. If any application require data after very short delays to detect an event in the monitored area and report data continuously to the base station than there will be a requirement of permanent connectivity in the network. In this case the area is needed to be permanently covered. In other cases, the monitored area is needed to be covered temporarily. Permanent connectivity is necessary in the applications where the data delivery model is continuous. Otherwise, an intermittent connectivity is sufficient. If the application requires a high degree of robustness, multiple paths toward the sink are needed. Otherwise, a single path is sufficient. A full or uniform deployment is needed in case the application concerns the quality of data gathered at each sensor network. In this case the application must specifies the time and space consistency of the gathered data.

II. RELATED WORK

In this section, a brief review of existing survey/review papers has been discussed and also some points which are different in our survey. The surveys on coverage and connectivity issues in deployment (2; 3; 4; 5; 6; 7; 8) introduce basic concepts related to coverage and connectivity. For instance, (2) focuses on how to ensure area coverage and how to deploy sensor nodes. (3) Classifies coverage problems as coverage based on exposure and coverage exploiting mobility.

Papers (4) and (5) classify and discuss the area coverage, point coverage and barrier coverage in detail. A significant difference between static coverage and dynamic coverage has been presented in (6). The authors also have proposed new sleep scheduling algorithm for minimizing the energy consumption in WSN and presented an analysis of coverage and connectivity problems. In (7) a review of existing distributed and centralized algorithms for deployment has been given. In (8) different deployment strategies have been presented by the authors and an analysis has been presented at the end of review. In (60) a study of various coverage and connectivity issues have been presented and analyzed using case studies. These surveys are good references to have an overall view of coverage and connectivity issues in WSNs.
In this review, a brief literature has been presented on connectivity and coverage to make better understanding of deployment strategies. The novelty of our review lies in the different study angles and providing comprehensive understanding of the coverage and connectivity in deployment in WSNs. Every coverage and connectivity problem has been represented with the help of understandable diagram. In the end of our paper we have discussed trends and open issues in this area. Different deployment algorithms have been compared and an analysis have been presented. Different algorithms for deployment has been discussed in connection with coverage and connectivity problems in WSNs. This survey will useful for the readers to gain knowledge of the coverage and connectivity problems as well as the better recognition of deployment strategies has been developed.

III. COVERAGE PROBLEMS

In WSN applications the area under consideration is said to be covered if and only if every point of interest is under the sensing range of at least single sensor node which is active throughout the lifetime of the network.

A. Area Coverage

The biggest problem in most of the applications of WSNs is to cover the whole area in sensing range of the network. The goal is to gather the factor value from each point of the area under consideration. The coverage depends on the requirement of the applications that it needs a full area coverage or partial area coverage. However, the number of sensors required for full and partial area coverage are different.

1) Full Coverage

Many of the applications of WSNs require a full area coverage. This type of requirement of applications every location should be covered by at least one sensor node (1-coverage) or by k sensor nodes, where k>1 (k-coverage). This technique may be expensive. However a full coverage and full connectivity ensures quality of the data to be gathered. Following types of full coverage are available:

a) Simple Coverage

In WSNs, it is necessary to ensure full coverage of the area under consideration while deploying the minimum number of sensor nodes. This can be achieved by covering each location in the area by using at least one sensor node. Each sensor node will gather information from their respective location and send this information to base station. In simple coverage the number of sensor nodes has been kept as minimum as possible by ensuring coverage and connectivity.

b) Multiple Coverage

When simple coverage is extended by multiple nodes covering single point location then it is called as multiple coverage and is denoted by k-coverage. Some applications such as critical area monitoring, distributed detection, mobility tracking and intelligence systems require multiple coverage. Multiple coverage required because simple coverage will produce certain data losses even when a single node failure occurs. The WSN deployment in which at least k nodes are covering single point of interest is called as k-coverage deployment. The sensor network in k-coverage can tolerate up to k-1 failures.

2) Partial Coverage

Some of the applications of WSN require not to cover the whole area but require partial area to be covered because the application task is not critical. In these type of applications partial coverage ensuring a given degree of coverage is sufficient and acceptable. Sensor nodes are deployed in such a way that they can cover at least p percent of area is known as partial coverage deployment and the coverage is called as p-coverage, where 0<p<1. Partial coverage is a method of saving the energy cost of sensor nodes and increasing the network lifetime since the number of sensor nodes deployed is less than the number required to fully cover the area considered. Figure 2 depict sensors deployment ensuring partial coverage.

B. Point Coverage

Many applications of WSNs require only monitoring of a specific points and not the whole area. Hence, there is a need of covering specific points only by at least one sensor node. Monitoring only specific points will increase the performance of the network. A better coverage and connectivity can be provided easily by using few sensor nodes at point of interests (Pol). Examples of point of interest monitoring, include monitoring of enemy troops and bases, capturing the real-time video material of possibly mobile targets. In such applications, mobile flying sensors can be deployed to monitor a point of interest. The PoI can be either fixed or mobile.

1) Fixed PoI

If same location is recorded for a PoI, then it is said to be fixed PoI. A fixed PoI is very easy to cover and monitor. Because there will be a prior knowledge will be available
about its position. Figure below gives an example of static PoI monitoring. In this example sensor nodes do not only cover the PoI but also maintain the connectivity with the sink to report detected events.

![Static PoI coverage](image)

Fig. 3: Static PoIs coverage.

2) Mobile PoI

If a point of interest changes its location again and again than it is called as the mobile PoI. Mobile PoI can be covered in two ways. One is to use the mobile sensors which can cover mobile PoI and keep a track of the movement of this PoI. Second, the static sensors can be used, but the deployment of static sensor nodes will be in such a way that every new position of the moving PoI can be covered by at least single sensor node. After collection of data a moving sink or sensor node should be used to gather data from all static sensors.

C. Barrier Coverage

Some of the important applications of WSNs require to monitor the border area of certain field to monitor or detect the intruders in that area. Examples of such applications involving movement detection are the deployment of sensors along international borders to detect illegal intrusion, around forests to detect the spread of forest fire, around a chemical factory to detect the spread of lethal chemicals, and on both sides of a gas pipeline to detect potential sabotage. The barrier crossing by intruders can be detected by using a barrier of the sensors at borders of the monitoring area. If the intruders try to cross this barrier of sensors then this movement will be detected by the sensor nodes and reported to the sink/base-station immediately. There are two types of barrier coverage: full barrier coverage or partial barrier coverage.

![Full barrier coverage](image)

Fig. 4: Full barrier coverage.

IV. CONNECTIVITY PROBLEMS

In WSN two sensor nodes are said to be connected if and only if they can communicate directly (one-hop connectivity) or indirectly (multi-hop connectivity). If there is at least a single path between the base station and the sensor nodes in the area under consideration than the wireless sensor network is considered to be connected. To monitor a specific area it is not enough to ensure coverage without considering connectivity. Every time when an event has been detected by sensor nodes it should be reported to the base station. Hence, the connectivity must be ensured for this task. There are two types of network connectivity: full connectivity and intermittent connectivity.

A. Full Connectivity

Connectivity in the network must not be ignored because all the data which will be transferred to base station require all nodes connected together. Hence, connectivity must be ensured in the network with respect to coverage in the network. Thus, to efficiently monitor a given area, many applications require not only full coverage but also full connectivity in order to collect information and report it. Just like coverage, full connectivity can also be both simple (1-connectivity) and multiple (k-connectivity).

1) Simple/Multiple Connectivity

If there is only a single path from each sensor node toward the base station then full connectivity is said to be simple connectivity. In multiple connectivity there will be multiple disjoint paths from sensor nodes towards the base station.

2) Preserved Connectivity

Preserved connectivity has been at the first stage where the nodes and the base station are connected at the beginning of the sensor network. This connectivity is maintained during the deployment process. Means anytime during process of deployment there should be a path between sensor nodes and base station.

3) Connectivity at the end of the Algorithm

The connectivity which is maintained after the deployment of sensor nodes. However, at the end of deployment algorithm execution it should guarantee full connectivity.

B. Intermittent Connectivity

Some applications of WSN do not require full connectivity of the network but require only alternating or irregular connectivity. This type of connectivity mostly required in the applications where there is a use of mobile sensor networks. The applications in this case require information from the disjoint components. There are two types of intermittent connectivity: the first one uses only one or several mobile sinks and the second uses a mobile sink and multiple throwboxes (Cluster heads).

![Intermittent connectivity](image)

Fig. 5: Intermittent connectivity

V. FACTORS AFFECTING DEPLOYMENT IN WSN

There are many factors impact the deployment of WSN sensor nodes and these also affect the performance and application requirements. The factors concern are:

- Assumption and model considered for the application affect the deployment and performance of the WSNs. Assumptions are totally dependent on the number of sensor nodes available for deployment and forming the network.

- The number of sensor nodes available for the deployment and the dimensions of the entity monitored will determine whether this number is sufficient to fully cover the entity monitored.

- Mobility of sensor nodes into the area of consideration is also a very important deciding factor. A manual or assisted deployment is required...
for in case of static sensor networks. A self-deployment will be done if mobile sensors have been used.

- Sensor nodes in WSN has limited energy and it will be difficult or almost impossible to renew. Mobile nodes during deployment consumes a lots of energy. Energy efficient deployment techniques must be used.
- The presence of obstacles makes the deployment more complex: no sensor node should be placed within an obstacle.

The data quality required by the application may lead to a uniform and regular deployment. Such a deployment provides smaller data gathering delays (9), a better time and space consistency of the data gathered, which leads to a more accurate snapshot of the measures taken.

VI. COMPARISON OF DEPLOYMENT ALGORITHMS

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Coverage type</th>
<th>Coverage problem</th>
<th>Connectivity type</th>
<th>Strategy</th>
<th>Cent/dest</th>
<th>Energy Efficiency</th>
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<tbody>
<tr>
<td>VFA (21)</td>
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<td>Permanent connectivity</td>
<td>Forces based</td>
<td>Centralized</td>
<td>Low</td>
</tr>
<tr>
<td>CPVF (27)</td>
<td>Area</td>
<td>Maximized coverage</td>
<td>Permanent connectivity</td>
<td>Forces based</td>
<td>Distributed</td>
<td>Low</td>
</tr>
<tr>
<td>Push &amp; Pull (28)</td>
<td>Area</td>
<td>Maximized coverage</td>
<td>Permanent connectivity</td>
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<td>Med</td>
</tr>
<tr>
<td>VEC, VOR and Minimax (40)</td>
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<td>Computational</td>
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<tr>
<td>CSP (53)</td>
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<td>Partial coverage</td>
<td>Intermittent connectivity</td>
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<td>Low</td>
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<td>PMS (53)</td>
<td>Barrier</td>
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<td>Random</td>
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<td>Low</td>
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</tbody>
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Table 1: Comparative Analysis of Deployment Algorithms

VII. OPEN RESEARCH AND TRENDS IN DEPLOYMENT OF WSN

Deployment is a fundamental issue in WSNs. For the deployment process many challenges have been studied and published in the literature. This survey has discussed the challenges in coverage and connectivity and given an analysis of the available deployment strategies deployment for WSNs. Several deployment issues are still unsolved and number of researchers across the world are working on these issues. Optimization in deployment process is a very critical task. If some researcher try to ensure connectivity then coverage will be compromised or if someone try to resolve the coverage issue than connectivity of the network will be compromised. Furthermore, the deployment algorithms must adapt to the changes in the technologies.

Sensor nodes can be deployed on a large scale to monitor the area under consideration. In short, sensor devices are becoming faster, more intelligent and heterogeneous. However, their autonomy is still limited by their embedded energy. Pushing back this boundary, energy harvesting and renewable energy are promising techniques to extend the lifetime of a battery and hence make them more autonomous.

Researchers must design new radio propagation models and new deployment strategies which can cope with new technologies and large scale wireless sensor networks. There is an introduction of UAVs (Unmanned Aerial Vehicles) and MUAVs, (Micro UAVs), swarms of flying and communicating UAVs and MUAVs will be used in monitoring applications. Security is an important issue in deployment algorithms, but is usually not addressed. An intruder could harm the deployment process and corrupt the data gathering. The deployment algorithms must become smarter enough so that the sensor nodes can adapt themselves to changes in environment.

VIII. CONCLUSION

This survey has presented two major challenges in WSNs: coverage and connectivity. Further we have given an analysis of some existing deployment algorithms with respect to coverage and connectivity issues. Two types of deployment algorithms has been presented i.e. static deployment algorithms and mobility based deployment algorithms. Deployment algorithms must meet the requirements of applications like coverage, connectivity, latency and robustness. This survey will helps the reader to gain knowledge of different coverage and connectivity types required by the applications of WSNs. The reader also get to know about the current trends and issues in deployment processes. We strongly believe that the deployment algorithms will undergo extensive development with the rapid emergence of the Internet of Things.

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