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Deployment strategies in the wireless sensor network: A comprehensive review

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ABSTRACT

Wireless Sensor Networks (WSNs) have come across several challenges such as node deployment, the reduction of power consumption, secure routing, bandwidth allocation, Quality of Service (QoS), and so forth. Since sensor deployment is an important matter due to its influence on cost and the network capability of WSN, the focus of this study is the deployment issue and related concerns such as coverage, connectivity, and energy efficiency, which have a great impact on the performance of WSNs. To the best of our knowledge, there are no studies that analyze and review the current scope completely. In this paper, some important research in the scope of sensor deployment will be investigated and analyzed as well as identifying their main specification. The deployment problem is classified based on few important factors and four deployment strategies and their related results are studied in each class. Also, the advantages and disadvantages along with important challenges of several strategies have been discussed so that more efficient deployment strategies can be developed in future.

1. Introduction

With the development of distribution environments such as the grid computing [30,44,70], cloud computing [12,43,47], Peer-to-Peer networks [46], Expert Cloud [8,26,28,43,50,54], electronic management [52,53,68,84,10], knowledge management [85,24] and MapReduce [45], nowadays, Wireless Sensor Network (WSN) becomes more popular than before. It is an emerging paradigm of computing and networking, which can be defined as a network of minuscule, diminutive, inexpensive, and keenly intellective devices, called sensor nodes. Sensor nodes are spatially distributed and they work cooperatively to communicate information gathered from the monitored field through wireless links and send them to a sink, which either uses the data locally or communicates it to other networks [59]. The development of WSNs was originally motivated by military applications [78], for example in battlefield surveillance they could be used to detect, locate, or track enemy movements. WSNs are currently employed in many industrial and civilian application areas including industrial process monitoring and control [57], environment and habitat monitoring [5,15,79], healthcare applications [4], home automation [66], and traffic control [42]. In the case of natural disasters [89], sensor nodes can sense and detect the environment to forecast disasters in advance. The wide range of potential WSN applications call for a rapidly growing multi-billion dollar market, but this would require further major progress in WSN standards and technologies to support new applications [21]. Despite the continuous development of WSNs, there are still several research challenges related to wireless sensor communication due to the restricted features of low priced sensor node hardware and the common necessity for the nodes to work for long time periods. Besides, there are challenges originating from close interaction between the WSN and the environment that need to be investigated, namely uncertainty related to sensors readings, harsh deployment environments and combining sensory data from multiple sensors [64].

For most WSNs, a major design step is to selectively decide the locations of the sensors in order to maximize the covered area of the targeted region. This particular problem has different appellations in the literature, e.g. placement, coverage or the deployment problem in WSNs [32]. The deployment of sensors can be random (e.g. dropping sensors in a hostile terrain or a disaster area) or deterministic (e.g. placing sensors along a pipeline to monitor pressure and/or temperature, and boundary surveillance) [27], and it depends mainly on the type of application, the environment, and the sensors themselves. The planning strategy of the deployment problem affects transmission rate of the sensors as well as the coverage and lifetime of the whole system, making the deployment a very critical issue in WSNs [74].

In general, poor deployment of sensor nodes leads to inefficient network connectivity or redundancy of coverage. A well-chosen deployment strategy will not only reduce cost but also extend the

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network lifetime; therefore, the deployment of a WSN is a critical problem. Deployment planning requires consideration of several objectives such as energy consumption, sensing coverage, network lifetime, network connectivity, and so forth. Often these objectives conflict with one another, and operational trade-offs must be established during network design [76].

In this paper, we classify the deployment methods and algorithms proposed in the literature for both predetermined and random deployments. This classification is based on the most important objectives used for modeling and solving the deployment problem. The deployment strategies are classified into four main categories: increasing the coverage, enhancing the connectivity, improving energy efficiency and optimizing the lifetime, and finally multi-objective deployments. To the best of our knowledge, a comparative study on the deployment issue considering these categories has not been conducted as of yet. [81] categorizes different approaches based on their node positioning techniques (static vs. dynamic [41]), and compares them based on their objectives and methodologies. However, it does not consider multi-objectivity of the strategies. [88] investigate the coverage and connectivity issues from different aspects of deployment strategy, sleep schedule mechanism and coverage radius. We have investigated state-of-the-art strategies in each category and depicted their advantages and disadvantages. We have compared all presented strategies based on some important factors regarding deploying sensors, such as load balancing, energy distribution, scalability, sensor's sensing range, a region of interest, network cost and so on. As well, a side-by-side comparison of all discussed strategies is presented, and few open issues are addressed.

The basic concepts and preliminaries are provided in the next section. Section 3 discusses related papers and research in the scope of sensor deployment under four main categories. The taxonomy and comparison of analyzed strategies are presented in Section 4. Section 5 maps out open-ended issues and finally Section 6 concludes the paper.

2. Basic concepts and preliminaries

The solutions to deployment issues in WSNs involve many basic theories and assumptions. In this section, some basic knowledge regarding WSN will be presented, and deployment concepts, and few definitions that are required to further understand the rest of the paper are provided.

2.1. Preliminary definitions

Definition 1. (Random deployment). In many practical cases, the random scattering of WSNs might be essential, because of the large scale of the required network or the inaccessibility of the terrain. Node placement must meet two conditions; nodes should not be placed too close, which would result in a small covered area and little information would be retrieved. Additionally, if nodes are placed too far apart, many would be isolated and as a result, data would not reach the sinks [76]. Random deployment may require much more redundant sensors to be deployed in order to achieve given specification.

Definition 2. (Pre-determined deployment). In pre-determined deployment, the locations of the nodes are specified. This type of deployment is mostly used in applications where sensors are expensive or their operation is meaningfully affected by their position, namely by placing imaging and video sensors, populating an area with highly precise seismic nodes, positioning WSN applications underwater, monitoring manufacturing plants etc. [20].

Definition 3. (Self-deployment). More recently, self-deployment is proposed as a technique assuming the sensors' own mobility. For example, potential fields [80] or virtual force based approaches [33] are used to spread sensors out from a compact or random initial configuration to cover an unknown area.

Definition 4. (Energy hole). Sensor nodes which are close to the sink have larger energy consumption because they carry heavier relay traffic. As a result, sensor nodes in this area tend to die early when their energy diminishes as a result of what is called an energy hole [22]. The non-uniform dissipation of energy in any part of the network may stop the functioning of that part of the network, leading to a phenomenon known as the energy hole problem. In order to solve the energy hole problem, a concept of non-uniform deployment for the sensor network has been proposed. In this concept, the area closer to the sink should have higher sensor density which enables a larger number of sensors to share the load of data-forwarding. [35].

Definition 5. (Heterogeneous wireless sensor network). Heterogeneous WSN contains sensor nodes with various abilities, such as a different processing power and sensing range, so deployment and topology control are more complicated when compared to homogeneous networks [7]. Energy consumption and lifetime tend to be the most important issues to have been found in heterogeneous WSNs, increasing the balance in energy usage enhances the network's lifetime [51].

Definition 6. (Homogeneous wireless sensor network). In homogeneous networks, each of the nodes is similar in battery energy and hardware complexity. Homogeneous wireless sensor networks with pure static clustering might increase the risk of cluster head nodes being overloaded with transmissions of extended range to remotely located base stations. Furthermore, extra processing is required for the protocol coordination and data aggregation [75].

Definition 7. (Relay nodes). Relay nodes can have extra storage space and much more powerful transceivers compared to sensor nodes. They can be used in order to forward sensed data for long distances in large monitored sites, and energy at Sensor nodes is saved for further data sensing and gathering [87].

Definition 8. (Redundant node). The redundant node refers to the node that can be removed from the network without affecting the process of receiving the targeted data. On the contrary, the irredundant node is a unique source of information in the monitored site that cannot be recovered by the other nodes in the network [86].

Definition 9. (Mobile node). Mobile nodes have all the features of the fixed nodes; in addition, they enjoy mobility feature. Since coverage and connectivity are crucial for WSNs, the failure of a node may cause the network to be partitioned into disjoint segments or brought along with a hole in the original coverage area. A mobile node can act as a router when it is in a low or even no coverage area, and it can accomplish the recovery task [88].

Definition 10. (Voronoi partition). Given k points in a plane, the plane is partitioned into k sub-regions according to the nearest-neighbor-rule [9] such that every sub-region called Voronoi cell is dominated by a point called Voronoi center which is closest to all the points in this sub-region. As an example, a Voronoi diagram is shown in Fig. 1 [36].

Definition 11. (mobile sinks). Mobile sinks are special nodes which visit the WSN at regular intervals in order to collect sensed data, thus, eliminate the need for multi-hop communications and reduce energy consumption significantly Yu, Zhang et al., [83]. Consequently, the use of mobile sinks extends the network lifetime when employed. It is not feasible to employ multi-hop communi-