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Deployment Techniques of Nodes in WSN for Multi-Domain Applications A Survey on their performance analysis

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Abstract

Wireless Sensor Network has been very interesting topic of research since many years. This survey paper focuses on performance comparison of different spatial Wireless Sensor Node (WSN) deployment algorithms that have been proposed and reviewed by many researchers through the years. The primary challenge will face in designing wireless sensor networks (WSNs) is to find tradeoff between the desired and contrary requirements for the lifetime, coverage or cost while coping with the computation, energy and communication constraints. This paper examines the optimal placement of nodes for a WSN. It is impractical to decide the deployment of the nodes separately from WSNs applications. This paper highlights the properties of WSNs applications which determine the placement problem. This work also identifies and analyzes the various objectives that should be considered while designing WSN. This paper also gives an overview and importance on multi-objective strategies, their assumptions, and optimization.

Keywords

Network coverage, Network lifetime, Node placement, Node re-positioning, wireless sensor network, Cluster-Head (CH), Data Collector (DC).

1. Introduction

In this paper we focus on optimal node placement algorithm in keeping all the constraints for multi-domain applications. This is one of the most important design steps to selectively decide the locations of the sensors to optimize the desirable objectives, e.g., maximization of the covered area or minimization of the energy use. Fundamental questions in this case include [1]:

- How many sensor nodes are enough to meet the overall system objectives?
- For a given network with a certain number of sensor nodes, how do we accurately deploy these nodes in order to increase network performance?
- When data sources change or some part of the network malfunctions, how do we adjust the network topology and sensor placement so that it should be fault tolerant?

In the past, a number of US-based research projects [3] established a de facto standard of a wireless sensor network as a large-scale, ad-hoc in nature; transmit using multi-hop, wireless un-partitioned network of mostly homogenous, tiny, resource-constrained, mostly immoveable sensor nodes that would be randomly placed in the area of interest [4]. In 1998 R¨omer and Mattern [2] proposed over ten properties characterizing existing WSN applications such as size, mobility, heterogeneity, communication modality etc.

Accurate node placement is a very challenging problem that has been proved by many researchers as NP-Hard complete problem [5–7]. To tackle such complexity, several heuristics have been proposed by many researchers to find near optimal solutions. However, the context of these optimization strategies is mainly concentrate as static, that means assessing the quality of candidate positions is purely based on a structural quality metric such as coverage area, duration of network connectivity are based on the analysis of a fixed topology. Therefore, this paper classifies them as static approaches for deploying nodes. On the other hand, some applications need dynamic adjustment of nodes location since the optimality of the initial positions may become not valid during the operation of the network depending on the network state and various external factor such as traffic patterns, the load may not be balanced among the nodes causing bottlenecks. Also, some application interest can vary over time and the available network resources may change as new nodes join the network dynamically, or as existing nodes lost energy.

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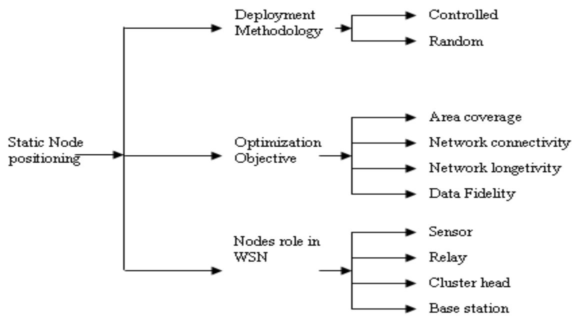

Figure 1: Different classifications of static strategies for node placement in WSN

The paper is organized as follows. The next section explains about static strategies for node positioning. The different techniques are classified considering the deployment scheme, the primary optimization metrics and the role that the nodes play. Section 3 will give attention to dynamic positioning schemes. This paper highlights technical issues and explains published techniques which exploit node repositioning schemes to enhance network performance and operation. Finally, Section 4 concludes the survey.

2. Static deployment of nodes

The position of nodes has impressive impact on the effectiveness of the WSN and the efficiency of its operation. Node placement schemes prior to network setup usually based on their choice of the particular node's position's on metrics like Area coverage and inter-node distance which are independent of the network state or assume a fixed network operation pattern that remains unchanged throughout the lifetime of the network. In this section we discuss some well known node placement strategies and techniques from the literature. We classify them according to the deployment methodology, the optimization objective of the placement and roles of the nodes. Figure 1 summarizes the different classes of node placement strategies to be considered.

2.1 Deployment methodology

Sensors can be placed in an area of interest either deterministically or randomly. The choice of the deployment scheme depends heavily on the type of sensors, application domain and the environment in which sensors have to operate. Controlled node deployment is feasible and often necessary when sensors are expensive or when their operation is significantly depends on their position. For such scenarios populate area of interest with highly precise seismic nodes, underwater WSN applications, and placing imaging and video sensors. On the other hand, for some of the applications random distribution of nodes is the only feasible option. This is particularly true for harsh environments such as a battle field or a disaster region. Depending on the node distribution methods and the level of redundancy, random node deployment method can achieve the required performance goals.

2.1.1. Controlled node deployment

Usually we have controlled deployment methods for indoor applications of WSNs. Examples of indoor networks include the Active Sensor Network (ASN) project at the University of Sydney in Australia [8], the Multiple Sensor Indoor Surveillance (MSIS) project at Accenture Technology Labs, in Chicago [9] and the Sensor Network Technology projects at Intel [10]. The ASN and MSIS projects are geared towards serving surveillance applications such as secure installations and enterprise asset management. Another notable effort is the Sandia Water Initiative at Sandia National Lab which addresses the problem of placing sensors in order to detect and identify the source of contamination in air or water supplies [8,9]. Deterministic placement is also applicable in applications like range-finders, underwater acoustics, imaging and video sensors. In general, these applications need sensors to be deployed in three-dimensions (3-D), which is much more difficult to analyze and compare the two-dimensional deployment methods.

2.1.2. Random node distribution

In some applications of WSNs like reconnaissance mission's combat, disaster recovery and forest fire detection deterministic deployment of sensors is very risky and/or infeasible. Randomized sensor placement often becomes the only option for the above said applications. It is widely expected that sensors will be dropped by helicopter, grenade launchers or clustered bombs. Such means of deployment lead to random spreading of sensors nodes. Even though the node density can be controlled to some extent but it is somewhat unrealistic. Many research projects, such as [11], have assumed uniform node distribution when evaluating the network performance. The rationale is that with the continual

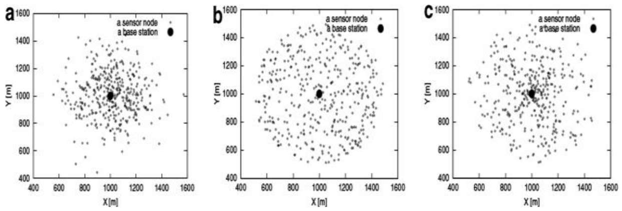

Figure 2: (a) simple diffusion (b) constant (uniform) placement and (c) R-random placement

decrease in cost and size of micro-sensors, a large population of nodes is expected in area of interest and thus it is reasonable to assume a uniform distribution. In 2004 Ishizuka and Aida [12] have investigated random node distribution functions, to capture the fault-tolerant properties of stochastic placement. They have compared simple diffusion, constant placement and R-random placement methods. The experiments have shown that tracking coverage and node reachability as well as data loss in a target tracking applications. The simulation results showed that the initially placed sensors have a significant effect on network dependability for tolerance of a node failure that may be a cause due to damage and battery exhaustion. The results also showed that the R-random deployment is a better placement strategy for fault-tolerance metric.

2.2. Primary objectives for deployment

Application developers certainly like the sensors to be deployed in a way that satisfies with the overall design goals. Therefore, most of the published node placement schemes in the literature have focused more on increasing area coverage, extending the network lifetime, boosting the data fidelity and achieving strong network connectivity. Some of the secondary objectives such as fault-tolerance and load balancing have also been considered. Most of the published work strives to maximize the design objectives first using the least amount of resources (sensor nodes) [14]. Obviously, meeting the overall design objectives through random node deployment is an utmost challenge for the designers. Meanwhile, although instinctively deterministic placement of nodes can theoretically meet all primary and secondary objectives of WSN, the hunt for minimizing the required network resources keeps the problem still very hard. In this section, we categorize published work according to the optimization objectives of the sensor placement.

2.2.1. Area coverage

At most attention has given for maximal network area coverage in the literature. Assessing the area coverage varies based on the underlying model of each sensors and the metric used to measure the collective coverage of deployed sensors. In 2003 C.-F. Huang, Y.-C. Tseng published work in [13], assumes a disk coverage zone centered at the sensor with a radius that equals its sensing range. However, some recent work has started to employ more practical models of the sensor's field of view in the form of irregular polygons [14]. In some of the published papers, they use the ratio of the covered area to the size of the overall deployment region as a metric for the quality of network coverage [13]. Since 2001, however, most work has focused on the worst case coverage, usually referred to as least exposure [15]. The advantage of exposure-based coverage assessment is the inclusion of a practical object detection probability that is based on signal processing formulations, e.g., signal distortion. As mentioned earlier, optimized sensor placement is not an easy task, even for deterministic deployment scenarios. Complexity is often introduced due to hunt for employing the least number of sensors in order to meet the application requirements and also by the uncertainty in a sensor's ability to detect objects due to distortion. Distortion may be caused by terrain of area or the sensor's presence in a harsh environment. Dhillon and Chakrabarty have considered the placement of sensors in grid fashion of the deployment region [11]. Basically the probability of detecting a target is assumed to decreasing at an exponential rate with the increase in distance between a sensor and that target. A sensor can detect targets that lie in its line-of-sight. An obstacle may make a target undetectable by the sensor. The sensing model is then used to identify the grid points on which sensors are to be placed, so that an application-specific minimum confidence level on object detection is met. They propose a greedy heuristic that strives to achieve the network coverage goal through the least number of sensors. In each iteration, a sensor is placed at the grid point with the least coverage as the algorithm is *iterative*. The algorithm terminates when the coverage goal is met or a bound on the sensor node count is reached.

2.2.2. Network connectivity

Unlike coverage, which has constantly been an objective or constraint for node placement, network connectivity has been considered as non-issue in some of the early works based on the assumption that the signal transmission range Tr of a sensor node is much longer than its sensing range Sr. The principle is that good coverage will yield a connected network when Tr is a multiple of Sr.

2.2.3. Network longevity

Extending network lifetime has been considered as the optimization objective for most of the published communication protocols of WSNs. The positions of nodes have significant impact on network longevity. For example, variations in node density throughout the area can eventually lead to unbalanced traffic load and cause performance bottlenecks [15]. In addition, a uniform node distribution may lead to depletion of energy of nodes which are close to the base-station at higher rate than other nodes which are not close to base-station and thus shorten the network lifetime.

2.2.4. Data fidelity

Ensuring the reliability of the gathered data is obviously an important design goal of WSNs. A sensor network basically provides a collective assessment of the detected phenomena by fusing the readings of multiple independent sensors. Data fusion maximizes the fidelity of the reported incidents by minimizing the probability of false alarms. Increasing the number of sensors reporting in a particular region will surely boost the accuracy of the fused data. But redundancy in coverage would require an increased node density, which is undesirable due to cost and other constraints such as the potentiality of detecting the sensors in a battle field.

3. Dynamic repositioning of nodes

Most of the protocols described in previous sections initially compute the optimal location for the sensor nodes and later do not consider movement of sensors once they have been fixed. Moreover, the context of the pursued optimization strategies is mainly static that means assessing the quality of candidate positions of sensors are based on performance metrics like the data rate, path length in terms of the number of hops from a sensor node to the base-station and sensing range etc. In addition, the placement decision is made at the time of network setup and does not consider dynamic changes being happened during the network operation. Application-level interest can vary over time, and the availability of network resources may change as new nodes come and join the network, or as older nodes exhausts their energy. Therefore, dynamic reposition of the nodes while the network is operational is very much essential to further improve the performance of the network. For instance, when many of the sensors in the locality of the base-station stop functioning due to the exhaustion of their batteries, some redundant sensors nodes from other locations of the monitored regions can be identified and relocated to replace the battery exhausted sensors in order to improve the performance and network lifetime. Such dynamic relocation of sensors while network is operational can also be very beneficial in an Automatic Target Recognition & Tracking (ATR) application where the target is in moving condition. The basic issues for dynamic node repositioning can be enumerated as follows (1) when does it make sense for a node to relocate (2) where should it go and (3) how will the data be routed while the node is moving?

3.1. Relocation issues

In this section we will try to answer the questions which asked in the previous section When to consider relocation: The decision for a node movement is motivated by either the performance measure at present is unacceptable or still we need the more efficient performance which is beyond what is achieving at the present node positions. Motivations vary based on the targeted design attributes. For example the observation of bottlenecks in data relaying decreases in node coverage in an area, increases in packet latency or excessive energy consumption is happening per delivered packet. A weighted average can also be considered to combine multiple metrics based on the application. Once a node has its motive, it will be considered to move to a new position. Such consideration does not always lead to an actual relocation. First the node needs to qualify the impact of repositioning at the new position on network performance and operation. Therefore the ‘‘when’’ and ‘‘where’’ issues of node movement are much correlated. In addition, the node must be analyzed to assess the relocation overhead. Such overhead can be incurred by the node and the network. Moreover, when energy and timeliness metrics are primary concern, the impact on the lifetime of individual sensors and the route maintenance has to be considered respectively. Where to relocate: When having a motive to relocate, the node needs to identify a new location that would satisfy the desired goals, example boost overall network performance etc., Again, the qualification of the new location and possibly the search criteria may vary based on the design attributes. Finding an optimal position for the node in a multi-hop network topology is a very complex problem. The complexity is due to two factors. The first is the potentially infinite number of possible locations that a node can be moved to. The second factor is the overhead to keep track the network and the node state information for determining the new position of node. In addition, for every short-term solution considered during the search for an optimal location for node, a new multi-hop network topology has to be established in order to compare that short-term solution to the current or previously picked locations. A node has to know the boundaries of the monitored region of interest, the current coverage ratio of the network, the location of dead sensor nodes or other information in order to determine its new position. It is impractical to search exhaustively for the best positions of the nodes for some typical WSN applications. In addition, the dynamic nature of the network makes the sources of data and node state to change rapidly; thus the optimization process may have to be repeated frequently. Moreover, it is undesirable to involve the nodes in complex computation since it diverts both the computation capacity needed for application-level processing, and the energy needed for movement of the node. That is why, approximations and local solutions, or search heuristics, are more popular in the context of WSNs [13,14]. Managing and justifying the move: Once the new location of the node has been identified and confirmed to enhance some desired attributes of WSN, the node should identify a travel path to the new position. The main factors which contribute to the path selection are the suitability of the terrain, total distance to be traveled by node, the path safety and the risk of disrupting the network operation. Minimizing the travel distance for the nodes is very crucial since the energy consumed by the mechanical parts of sensors in such a movement is much more than the communication and computational energy. Therefore, the optimal shortest path should be identified and selected to reach the new location. The nodes also have to identify and select an optimal path that is physically feasible to travel.

3.2. Sensor repositioning schemes

While the bulk of published research work envisions sensors to be stationary, some investigations showed the possibility of attaching sensors to moveable entities such as robots [16, 17]. Sensor mobility has been exploited to increase the performance of WSNs. For example, mobile sensors can re-distributed in an area to ensure uniform network coverage, move closer to heavily loaded nodes in order to prevent performance bottlenecks or increase bandwidth by carrying data to the base-station [10, 18]. Proposed schemes for dynamic sensor re-positioning in the literature can be categorized into two groups, based on when relocation is considered into post-deployment or on-demand relocation. These two categories of relocation are discussed in detail in next section.

3.2.1. Post-deployment sensor relocation

This type of relocation is pursued to the conclusion of the sensor deployment phase when the sensor nodes are being positioned in an area of interest. As we discussed in earlier sections, in most of the WSN applications, sensor deployment is performed randomly due to the inaccessibility of the monitored areas. However, this random deployment usually does not provide adequate coverage of the area unless an excessive number of nodes are deployed in area. Alternatively, the quality of coverage can be improved by distributing the sensor nodes if they are able to do so. In that case, sensor nodes can be relocated to the new regions with inadequate coverage, or no coverage at all. Considering the energy cost of mechanical movement and the communication overhead involved in directing the motion, the relocation of new position process should be lightweight and should conclude in a reasonable way. In 2004 G. Wang, G. Cao, T. La Porta [18] proposed that, the primary goal is to maximize the network area covered within the shortest time duration and with minimal communication overhead in terms of travel distances and inter-sensor message traffic. The main idea is that each sensor assesses the network coverage in its locality after deployment and decides whether it should move to increase the network coverage. In order to assess the network coverage, a sensor node creates a Voronoi polygon with respect to neighboring sensor nodes. In order to decide where to reposition a sensor to new location, three methods have been proposed: *vector-based (VEC), Voronoi-based (VOR)* and *Minimax*.

3.2.2. On-demand repositioning of sensors

Instead of relocation of the nodes at the deployment phase, sensors can be relocated on demand basis to improve certain performance metrics such as coverage, network lifetime and etc., the new location can be decided during the network operation based on the changes in either application-level or the network state. For instance, the application can track a fast moving target which may require repositioning of some sensor nodes based on the new position of the target. Furthermore, in some applications there can be an increasing number of non-functioning nodes in particular part of the area of interest, which makes necessity in redistribution of available sensors nodes. In addition to improving the network coverage, the energy consumption can be reduced through on-demand reposition of sensors in order to reach the best performance and efficient topology.

3.3. Repositioning data collectors

As discussed earlier, sensor data is collected at either the base-station or Cluster Head (CHs) for aggregation and additional processing consistent with the computational capabilities of such data collectors (DCs). Dynamic relocation of DCs has also been pursued as a means for increasing network performance, dealing with traffic bottlenecks and preventing interruptions in operations of network. Unlike sensor relocations, the goal for relocating DCs is usually not only to the individual node and involves numerous network state parameters.
In this section, we just list out approaches that consider a single DC or uncoordinated repositioning of multiple DCs. Repositioning of data collectors are mainly because of the following:

1. Relocating for increased network longevity
2. Enhancement of timeliness of delay-constrained traffic Maintenance of uninterrupted network operation

4. Research issues and challenges

This paper shows that there are many different algorithms to deploy node meeting all the design goals of the applications. However, there still exists a number or issues and problems that need to be addressed in future research work. One of the deployment techniques [22], which is Random type node placement algorithm for generic applications. But this algorithm still fails to serve the energy efficiency. Algorithm given by [33] is deterministic method of deploying nodes, but still fails to cover the network efficiently.

Table 1: A comparison between the various approaches for nodes deployment for multi-domain application

Paper	Application	Space	Deployment	Node type	Primary objective	Secondary objective	Constraint
[5] A. Efrat, S. Har-Peled, J.S.B. Mitchell	Generic	2-D	Deterministic	Data collector	Network lifetime	-	-
[19] X. Cheng, DZ Du, L. Wang, B. Xu	Biomedical SN	2-D	Deterministic	Relay	Network lifetime	Min relay count	connectivity
[20] J. Pan, L. Cai, Y.T. Hou, Y. Shi, S.X. Shen	Generic	2-D	Deterministic	Data collector	Network lifetime	-	-
[21] S.S. Dhillon, K. Chakrabarty	surveillance	2-D	Deterministic	Sensor	Coverage	Min. sensor count	-
[22] T. Clouqueur, V. Phipatanasuphorn, P. Ramanathan and K.K. Saluja	Outdoor	2-D	Random	sensor	Data fidelity & coverage	Min. sensor count	-
[23] J. Berry, L. Fleischer, W.E. Hart, C.A. Phillips	Contaminati on detection	2-D	Deterministic	Sensor	Coverage	–	Fixed sensors count
[24] J.-P. Watson, H. Greenberg, W.E. Hart	Contaminati on detection	2-D	Deterministic	Sensor	Coverage	Delay	Fixed sensors count
[25] J. Tang, B. Hao, A. Sen	Outdoor	2-D	Deterministic	Sensor	Min. relay count	Fault-tolerance	Connectivity
[26] M. Ishizuka, M. Aida	Outdoor	2-D	Random	Sensor	Coverage & connectivity	Fault-tolerance	-

[27] D. Pompili, T. Melodia, I.F. Akyildiz	Underwater	2-D	Deterministic	Sensor	Coverage	Min. sensor count	-
[28] E.S. Biagioni, G. Sasaki	Outdoor	2-D	Deterministic	Sensor	Coverage & connectivity	& Fault-tolerance	–
[29] K. Kar, S. Banerjee	Outdoor	2-D	Deterministic	Sensor	Coverage & connectivity	Min. Sensor count	–
[30] J. Bredin, E. Demaine, M. Taghi Hajiaghayi, D. Rus	Outdoor	2-D	Deterministic	Sensor	Connectivity	Fault-tolerance	–
[31] S. Toumpis, G.A. Gupta	Massively dense networks	2-D	Random	Sensor	Min. sensor count	Delay and energy	–
[32] K. Dasgupta, M. Kukreja, K. Kalpakis	Surveillance	2-D	Controlled (nodes move)	Sensor	Network lifetime	–	Coverage
[33] A. Bogdanov E. Maneva, S. Riesenfeld	Generic	2-D	Deterministic	Data collector	Max. data flow	Min. energy	–
[34] E.I. Oyman, C. Ersoy	Generic	2-D	Deterministic	Data collector	Network lifetime	Min. CH count	–
[35] K. Akkaya, M. Younis	Generic	2-D	Random	Data collector	Coverage	Delay	–
[36] S.R. Gandham, M. Dawande, R. Prakash, S. Venkatesan	Generic	2-D	Deterministic	Data collector	Network lifetime	Load balancing	–

5. Conclusion

This paper studied and investigated some well known deployment issues, which is a fundamental problem correlated to the quality of service for WSN applications. We shed some light on the importance of the deployment algorithms. Then we start with several definition issues that are correlated to the modeling of the deployment problem, such as the localization techniques and sensor model. We classify the deployment algorithms into two main classes, random deployment and deterministic deployment. In static approaches of node placement, optimized node placement is pursued in order to achieve desired properties for the network topology and network coverage. On the other hand, dynamic repositioning of senor nodes after deployment can be a viable means for increasing the performance. We have identified the technical issues to relocate the nodes; namely when to reposition a node, where to move it and how to manage the network while the node is in mobile condition. We have surveyed published techniques for node positioning and compared them according to their objectives, methodologies and applications. This survey concludes that static strategies are more practical when a deterministic node placement is considered and when the cost of nodes is not an issue. This survey also concludes that random deployment of nodes does not give much improved performance however deterministic approaches can boost the performance for some applications only random style of deploying nodes is only possible.

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