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The Deployment in the Wireless Sensor Networks: Methodologies, Recent Works and Applications

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Abstract The wireless sensor networks (WSN) is a research area in continuous evolution with a variety of application contexts. Wireless sensor networks pose many optimization problems, particularly because sensors have limited capacity in terms of energy, processing and memory. The deployment of sensor nodes is a critical phase that significantly affects the functioning and performance of the network. Often, the sensors constituting the network cannot be accurately positioned, and are scattered erratically. To compensate the randomness character of their placement, a large number of sensors is typically deployed, which also helps to increase the fault tolerance of the network. In this paper, we are interested in studying the positioning and placement of sensor nodes in a WSN. First, we introduce the problem of deployment and then we present the latest research works about the different proposed methods to solve this problem. Finally, we mention some similar issues related to the deployment and some of its interesting applications.

Keywords WSN, optimization, deployment, positioning, coverage, energy, connectivity.

I. INTRODUCTION

The performance of a wireless sensor network is greatly influenced by the process of deploying the sensor nodes. The issue of deployment and positioning of sensor nodes in a WSN is a strategy which is used in defining the topology of the network, the number and the position of the sensor nodes. Quality monitoring, connectivity, and power consumption are also directly affected by the network topology. The problem of optimal placement of nodes is proven NP-hard for most deployment formulations [1]. The deployment activities can be grouped under three main phases. A pre-deployment and deployment phase that concerns the manual placement of the nodes by a human or a robot, or launching them from a plane (a helicopter or a drone). A post-deployment phase which is necessary if the network topology has been evolved due to a displacement of nodes, or a change of radio propagation conditions. The third phase is the redeployment which consists in adding new nodes to the network to replace some broken down or damaged nodes. Fig. 1, Fig. 2 and Fig. 3 illustrates the different deployment phases.

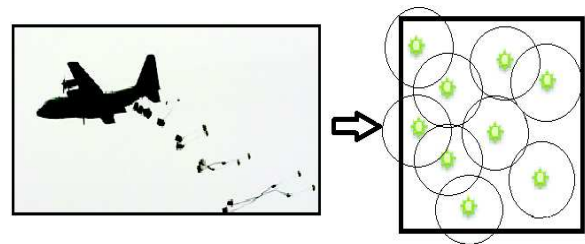


Fig. 1. Pre-deployment/Deployment phase

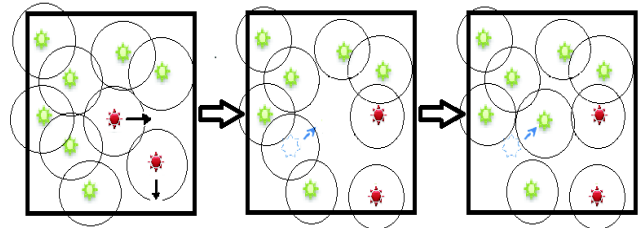


Fig. 2. Post-Deployment phase

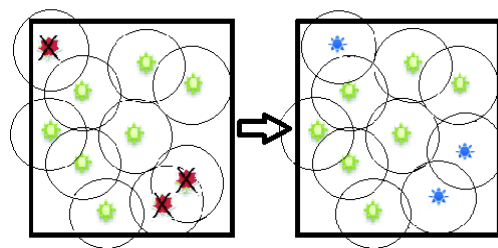


Fig. 3. Re-Deployment phase

Different issues are discussed at the deployment of sensor nodes in a WSN. These studies concern mainly stationary and mobile case, mono and multi-objective case, deterministic and stochastic case, and finally the static and dynamic case. In the dynamic deployment context for example, authors in [2] present and discuss different research works that aim to provide repositioning schemes nodes and some related problems. Authors in [2] propose a detailed study of the deployment in the static case. They distinguish two deployment methodologies depending on the distribution of

nodes (either random or controlled). Different primary objectives are treated:

- Coverage: it is among the most predominant issues to ensure the quality of service in a WSN. Several types of coverage are presented: area coverage, barrier coverage and point (event or moving target) coverage. Fig. 4 presents the different coverage types.
- Optimization of the energy consumption by nodes and assurance of the energy efficiency,
- Network connectivity,
- Lifetime of the network,
- Network traffic,
- Reliability of data
- Cost of deployment (the number of deployed nodes)
- Fault tolerance and load balancing between nodes.

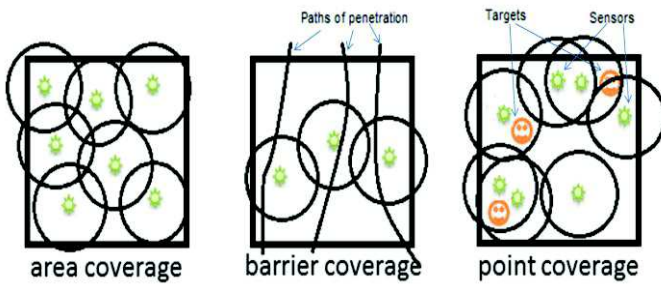


Fig. 4. Coverage types

In what follows, we discuss centralized, decentralized and hybrid approaches to solve the problem of deployment. Then, we present some similar problems and applications of the deployment.

II. RECENT WORKS AND RESOLUTION METHODOLOGIES OF THE DEPLOYMENT

A. Centralized approaches

Different centralized approaches are developed and tested to resolve the issue of node deployment in a WSN. Among other, we cite the following approaches: Bernoulli algorithms (BDA), approaches based on the Voronoi partition (VPA), approaches based on virtual forces (VFA), the potential field algorithm (PFDA), the differentiated deployment algorithm (DDA), the evolutionary optimization approaches and the collective intelligence paradigms. Hereafter, we present the various recent works in this context.

The virtual force algorithms (VFA) are popular approaches to the problem of coverage and node deployment. Indeed, nodes are considered as points which are subjected to a force of attraction and repulsion between them and which can move according to the calculated force. In the work of [3], an algorithm for the deployment of mobile sensor based on the Van Der Waals force is provided. Indeed, a frictional force is inserted into the force equation. The adjacency relationship between nodes is defined by the Delaunay triangulation. The calculated force produces acceleration for nodes to move. A metric evaluation called a per pair correlation function is introduced to evaluate the uniformity of the distribution of the nodes.

In [4], authors were interested in self-organizing networks with collective swarm intelligence. They present different aspects of bio-inspired mechanisms and examine different algorithms that have been applied to self-organizing networks. They are interested in existing bio-inspired algorithms such as ant colony algorithm, the bee algorithm and the particle swarm optimization. They also present and discuss various problems of self-organized from the point of view of physical layer, MAC layer and the network layer.

The works of [5] propose a multi-objective methodology for solving the deployment and power assignment problem. This evolutionary algorithm is based on the MOEA/D (Multi Objective Evolutionary Algorithm/Decomposition). This problem is decomposed into a set of scalar sub problems which are classified into goals according to their preferences. These goals are processed in parallel using the neighbor information's and specific evolutionary operators. At each iteration of the proposed evolutionary algorithm, operators adapt and dynamically set the requirements and preferences objectives for each sub-problem. According to their numerical results, the MOEA/D algorithm is better than the NSGAI for different instances.

In their works, the authors of [6] change the equation of the onlooker bee and scout bee of the original artificial bee colony (ABC) algorithm. Indeed, some new parameters are introduced such as forgetting and neighboring factor to accelerate the speed of convergence and the probability of mutation in order to maximize coverage. According to them, comparing with the deployment based on the original ABC algorithm and the original particle swarm optimization, this approach gives better performance in terms of speed of convergence and coverage with less need to move sensors.

Authors in [7] present a genetic algorithm aiming to resolve the problem of coverage holes in the network. The proposed algorithm determines the minimum number and the best locations of mobile nodes that must be added after the initial deployment of fixed nodes. The performance of the proposed genetic algorithm was evaluated using several indicators, and the simulation results show that this algorithm optimizes the network coverage in terms of coverage ratio and total number of additional mobile nodes.

Works of [8] aim to study various multi-objective approaches to solve the problem of sensor deployment according to different parameters (coverage, scalability, connectivity, cost, lifetime, latency). The authors present different studies based on genetic algorithms and those based on particle swarms. They also have present different simulation environments in the multi-objective case. The proposed simulation is divided into two phases. The first phase consists in simulating the nodes behavior and the results are optimized until achieving convergence. The second phase consists in feeding a network simulation results to verify the solution found.

Works in [9] study the problem of WSN deployment in terms of coverage and energy consumption of mobile nodes. Five algorithms are developed to maximize the detection range and to minimize the energy consumption (in order to maximize the lifetime). These algorithms provide the

possibility of redeployment when certain number of nodes becomes inoperative. Two centralized optimization algorithms are developed; one is based on the particle swarm optimization (PSO) and the other is based on genetic algorithms (GA). The latter algorithm is used to determine the optimal tradeoff between the ratio of network coverage and the overall distance traveled by the mobile nodes with a fixed radius of detection. The PSO algorithm is used to ensure network coverage and to minimize the consumed energy by mobile nodes with adjustable sensing ranges. According to their results; while optimizing energy; this algorithm can extend the life of the sensor between 1.4 and 10 times.

In their research, the authors of [10] addressed the problem of static deployment of wireless sensor networks. Their research work aimed at satisfying and valuing the following purposes: the cost of deployment (number of nodes), the quality monitoring, the network connectivity, and the network lifetime. The authors propose several heuristics deployment strategies and address the problem in three stages. In the first step, they consider only the deployment cost and the monitoring quality. They propose a new

deployment strategy called differentiated deployment algorithm based on image processing and 3D modeling. In the second stage, they extend the work of the first step by adding a third objective which is the network connectivity. Indeed, they offer two deployment strategies based on the tabu search meta-heuristic. The first strategy is the Bernoulli deployment algorithm, which is a probabilistic strategy in which the decision to deploy or remove a node follows a Bernoulli distribution. The second strategy is the potential field deployment algorithm which is a deterministic method based on one of the robotic principles: the virtual forces.

In another context, the works of [11] aim to benefit from redundancy of nodes to realize coverage and connectivity of sensor nodes. Authors proposed a method which starts from a random deployment and decides the need to ensure the connectivity. It achieves it if needed and then, finish the coverage. Indeed, the proposed method initially identifies islands (the amount of sensor nodes able to communicate), elects a chief node for each island and then it let robots travel through area and decides to cover found hole. In the Table I, we describe the centralized approaches used to solve the deployment.

TABLE I. CENTRALIZED APPROACHES FOR DEPLOYMENT

| Paper | [Author,Year] | Space | Deployment | Approach(es) | Objective(s) | Constraint(s) |
|-------|-------------------------------|-------|---------------|---|--|---|
| [09] | [Qu et al., 2013] | 2D | Deterministic | Multi-objective Genetic Algorithm | max Coverage min moving Energy | 100% coverage Lifetime: Less 50% energy High complexity |
| [09] | [Qu et al., 2013] | 2D | Deterministic | Particle Swarm Optimization | max coverage min Sensing Energy | 100% coverage Lifetime: Less 35% energy High complexity |
| [09] | [Qu et al., 2013] | 2D | Deterministic | Hybrid PSO | max coverage min Sensing Energy | 100% coverage Lifetime: Less 30% energy High complexity |
| [07] | [Banimelhem et al., 2013] | 2D | Binary | Genetic Algorithms | min node number coverage | mobile targets coverage |
| [05] | [Konstantinidis et al., 2009] | 2D | Deterministic | Multi-objective evolutionary algorithm + Decomposition (MOEA/D) | max coverage max lifetime | - |
| [10] | [Saadi, 2010] | 2D | Deterministic | Differentiated Deployment Algorithms | cost (node number) monitoring quality | - |
| [08] | [Aval et al., 2012] | 2D | - | Genetic Algorithms + Particle Swarm Optimization | coverage, connectivity, Lifetime | Simulation environments |
| [06] | [Yu et al., 2013a] | 2D | - | Artificial Bee Colony | max coverage rate | - |
| [03] | [Yu et al., 2013b] | 2D | - | Virtual Forces Algorithm + Van Der Waals Forces | Coverage | mobile sensor networks |

B. Distributed approaches

In addition to the centralized approaches, we found the distributed approaches that exploit the benefits of distribution to better solve the problem of deployment. In this context, the works of [9] studied the problem of deployment of WSN in the distributed case. Three algorithms for distributed optimization are developed without the use of a central node to replace the nodes, and optimize the coverage. Each algorithm is executed cooperatively by all nodes that communicate with each other and use limited information to relocate and achieve better coverage. Two of these algorithms use the relative positions between nodes for the coverage and optimize energy consumption. They permit to decrease the energy consumption between 20% and 25%. The third

algorithm is, according to the authors, the first algorithm developed for networks without the possibility of self-localization. Indeed, localization aims to determine the coordinates, in a reference, of a set of sensors nodes that we do not know their positions (coordinates) beforehand. In general, there are two types of coordinates: A global coordinates that provide information on the physical position of the located object on the globe (longitude, latitude) or in space (longitude, latitude, altitude). And a Relative coordinates which is a transformation (translation, rotation, reflection) of the global coordinates [12]. This third algorithm of [9] supports the optimal deployment of such networks without requiring the use of geolocation equipment or optimizing energy consumption for the localization algorithms. According to them, this is important for the inside

surveillance applications because the existing localization algorithms cannot easily provide a good accuracy for the redeployment of sensors in indoor environments. In the

Table II, we describe the different distributed algorithms used by [9].

TABLE II. DETAILS OF THE DISTRIBUTED APPROACHES PROPOSED IN [9]

| Space | Deployment | Approach(es) | Objective(s) | Constraint(s) | Coverage | Energy | Complexity |
|-------|---------------|---|---|---|----------|--------|------------|
| 2D | Deterministic | Optimization with Average Relative Position between sensors | max sensing range; min energy consumption | sensor relocation | 95%+ | 80% | Low |
| 2D | Deterministic | Optimization with Weighted Relative Distance | Coverage Lifetime | sensor relocation Fault tolerant | 95% | 100 | High |
| 2D | Deterministic | Sensing range Adjustment algorithm | coverage Sensing Energy | - | 100% | 20-50% | Medium |
| 2D | Deterministic | Without Localization algorithm | Coverage | non fault tolerant; developed for networks without self-localization capabilities | 94% | 130% | Low |

Authors in [13] and [14] used an approach based on a distributed virtual forces algorithm (DVFA) to establish coverage and connectivity taking into account the existence of obstacles in the covered area. They simulate the proposed algorithm using NS2 and compare their result with the centralized version of the virtual forces algorithm (CVFA). Their result shows that DVFA is more efficient than the CVFA in terms of coverage and connectivity.

C. Hybrid approaches

Hybrid approach consists in using two or more methodologies simultaneously to solve the problem. An important point is to find the correct hybridization pattern and to know how to combine these methods to extract their benefits. In this context, various hybridizations are proposed. Among others, the following are discussed:

Authors in [10] solved the problem of deployment by considering all the above objectives simultaneously. The proposed strategy is called multi-objective deployment algorithm and based on a virtual forces and a multi-objective tabu search algorithm.

In [15], the authors propose new hybrid version of the BBO (Biogeography based optimization) which is among the most recent meta-heuristics to solve global optimization problems with continuous variables and without constraints. This new hybrid version of the BBO has the objective of preventing the slow convergence and the lack of diversity in the BBO algorithm. The first proposed hybridization is to combine the BBO algorithm with the DE (differential evolution) algorithm to resolve unconstrained optimization problems, especially the multi-modal ones. The second proposed hybridization is to use three new variants of the BBO to solve constrained optimization problems. To test the proposed methods, authors aim to solve the power assignment and allocation problem in order to detect the

deterministic signal in a WSN in a decentralized manner. Their overall objective was the minimization of the allocated energy to the sensor nodes, ensuring low error detection probability. Having the same objective, a second application is proposed. It consists in segmenting images in grayscale with a multi-level thresholding using a fuzzy variant of the BBO algorithm (DBBO-Fuzzy).

Works of [16] study one of the parameters of quality of service in a WSN which is the coverage. The coverage must be insured so that the consumed energy of the sensors is minimized in order to increase the lifetime of the network. The authors propose an algorithm of particle swarm optimization hybridized with a differential evolution algorithm. A PSO algorithm is implemented to compare the effectiveness of the hybrid model in the same situation. Experiment results shows that the hybrid algorithm allows a longer network life and a more optimized use of the consumed energy. Furthermore, authors in [17] proposed a system based on the PSO and the Voronoi diagram algorithm. The PSO is used to determine the deployment scheme of the sensors to ensure optimal coverage while the Voronoi diagram is used to evaluate the objective function of the solution.

Moreover, the works of [18] aim at maximizing the coverage area in a WSN using a probabilistic model. An algorithm named CSAP (clonal selection artificial physics optimization algorithm) is proposed. This algorithm is a combination of two algorithms: the APO (artificial physics optimization algorithm) and the CSA (clonal selection algorithm). The APO is used to update the overall objective while the CSA is used to allow the previous algorithm to escape from local optima.

In the Table III, we describe the hybrid approaches used to solve the deployment.

TABLE III. HYBRID APPROACHES FOR DEPLOYMENT

| Paper | [Author,Year] | Space | Deployment | Approach(es) | Objective(s) | Constraint(s) |
|-------|-----------------------|-------|-----------------------------|---|---|------------------------------|
| [16] | [Maleki et al., 2014] | 2D | Deterministic | Hybrid (Particle Swarm Optimisation + Differential Evolution Algorithm) | max coverage area | Coverage Lifetime |
| [18] | [Hui et al., 2013] | 2D | Probabilistic | clonal selection algorithm + artificial physics optimization algorithm | max coverage area | - |
| [15] | [Boussaid, 2013] | 2D | Deterministic | Hybrid: Biogeography based optimization + Differential Evolution Algorithm | min total power allocated to sensors | - |
| [10] | [Saadi, 2010] | 2D | Probabilistic Deterministic | Bernoulli Deployment Algorithm +Potential Field Algorithm +Virtual Forces Algorithm | cost (node number) monitoring quality connectivity | - |
| [10] | [Saadi, 2010] | 2D | Deterministic | Virtual Forces Algorithm + multiobjective Tabu search | cost (node number) monitoring quality connectivity Lifetime | - |
| [09] | [Qu et al., 2013] | 2D | Deterministic | Hybrid Particle Swarm Optimisation algorithm | max coverage, min energy consumption | No need to self-localization |

III. SIMILAR PROBLEMS AND APPLICATIONS

Several similar issues are considered and different applications have been deployed using the mentioned approaches. In this context, authors in [19] study the problem of optimizing consumed energy while assuring the coverage in the WSN. They detail the WSN design factors and present different problems which are similar to the coverage in WSN. They are particularly interested in the *Art Gallery Problem*, the oceans coverage problem and the coverage robotic systems problem. The energy optimization problems are treated either on the basis of coverage areas (energy efficient area coverage), or according to coverage points (energy efficient point coverage).

The holes coverage in the sensing field is another problem in relation to the deployment issue. Indeed, these holes are usually caused by failures of sensor nodes and hostile environments (battles regions or volcanic regions) or by the random deployment of stationary nodes in the networks which consists of hybrid sensors (static and mobile nodes). For this, mobile nodes are often added after the initial deployment to overcome the problem of coverage holes. However, due to the low power of mobile nodes, the effective management of their movements to maintain coverage and network connectivity while minimizing the energy consumption becomes a challenge. Among the research works interesting in the resolution of the coverage problems, those proposed in [20] which try to solve the coverage problem in DNS (*Directional Sensor Networks*). Indeed, directional nodes are often equipped by ultrasound sensors, video sensors or infrared sensors. They differ from traditional omnidirectional nodes in several parameters such as the angle of view, the operating direction and the field of vision. Authors classify existing approaches and algorithms solving the problem of network coverage and determine their complexities, specificities and performance. They distinguish four main classes for the optimization methods: optimizing coverage based on targets, optimizing coverage based on

coverage areas, optimizing coverage with guaranteed connectivity, and extending the network lifetime. They define the detection models, the envisaged challenges for the DNS and their (dis)similarities with the WSN. Authors in [20] specify the advantages and disadvantages of DNS mobility and motility in terms of coverage and network lifetime.

In the same context, the authors in [21] develop an adaptive algorithm named AHCH (*Adaptive Hole Connected Healing*) to solve the problem of holes with guaranteed network connectivity without the need to find a new deployment scheme from zero. Indeed, this algorithm adapts the existing deployment scheme to avoid coverage holes. To prove the effectiveness of this algorithm, the authors compare, for different time intervals, the optimal solution with the estimation of the adaptive approximation ratio of this algorithm, with a complexity of $O(\log |M|)$, where M is the number of mobile sensors used for specific cases. Then, they extend this algorithm in the general case by establishing two other versions to solve the same problem with proof of their theoretical corresponding adaptive approximation ratios. The first version is called InAHCH (*Insufficient AHCH*) which is used to solve the problem of holes in the case where the number of mobile sensors is insufficient to guarantee a k -coverage for all holes. The second version is called GenAHCH (*General AHCH*) which is a generalization of the specific cases handled by the AHCH algorithm.

For military applications, the submarine deployment is one of the most interesting applications. Indeed, due to the complexity of the deployment environment in the three-dimensional spaces (3D) and the specific characteristics of the underwater acoustic channels, many factors must be taken into account. Thus, deployment issues in underwater environments are quite different from those of the WSN. In this regard, the works of [22] provide an overview of recent progress in the deployment algorithms in underwater environments. The authors classify the deployment algorithms into three categories, depending on the mobility of

sensor nodes: static deployment, self-adjusting deployment and deployment with assisted movement.

Another interesting and innovative application is the “Precision Agriculture” which aims at proposing solutions for agriculture to enhance the efficiency and to optimize the decision making in farming. In this context, authors in [23]

studies the different deployment used modes to resolve the Precision Agriculture challenges. They also present new approaches of gathering environmental information’s in order to minimize the deployment cost. Table IV summarizes the recent deployment applications.

TABLE IV. HYBRID APPROACHES FOR DEPLOYMENT

| Paper | [Author, Year] | Application(s) |
|-------|-------------------------|---|
| [09] | [Qu et al., 2013] | mobile wireless sensor networks indoor monitoring applications |
| [15] | [Boussaid, 2013] | signal detection segmenting images in grayscale |
| [10] | [Saadi, 2010] | image processing 3D modeling |
| [20] | [Guvensan et al., 2011] | Directional WSNs |
| [22] | [Han et al., 2013] | Acoustic sensor networks Submarine sensor networks |
| [24] | [Asma et al., 2014] | Aged persons monitoring in intelligent homes |
| [25] | [Manel et al., 2014] | declarative approach for monitoring intelligent buildings |
| [23] | [Nour et al, 2013] | Precision Agriculture |

IV. CONCLUSION

In this paper, we have presented and discussed the latest research works and the different strategies and approaches used by the scientific community to solve the problem of deploying sensor nodes in a wireless sensors network. Also, we have presented different similar problems and different deployment applications. According to our studies, the most recent research work began to turn especially to the hybrid methods to take advantage from the different methodologies. The works mentioned in this paper are also interested in the application of the distributed methods in the case of massive deployment (a large number of nodes) and the application of the optimization metaheuristics to resolve the problem of positioning and deploying sensor. The use of the latter approach is justified by the need to satisfy different objectives (often contradictory) as optimizing the energy consumption or the load balancing between nodes, maximizing the network connectivity, the network lifetime or the network traffic, and minimizing the number of deployed nodes or the fault tolerance of the network. Nevertheless, it is necessary in some cases to relax some constraints to minimize the search space and to have a near to optimal solution but within a reasonable time. In this case, the real test of the proposed approaches is often impossible; we resort to simulations to prove the efficiency of these methods.

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