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Multi-objective optimization in sensor networks: Optimization classification, applications and solution approaches

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ABSTRACT

A number of the practical scenarios relating to sensor networks are modeled as multi-objective optimization formulations where multiple desirable objectives compete with each other and the decision maker has to choose one of the tradeoff solutions. These multiple objectives may or may not conflict with each other. Keeping in view the nature of the application, the sensing scenario and input/output of the problem, the type of optimization problem changes. To tackle different nature of optimization problems relating to sensor network design, deployment, operation, planing and placement, there exist a plethora of optimization solution types. We analyze the existing literature to show the trend of the research community with respect to sensor network technologies being used, different engineering applications, simulation tools being used and the research emanating from different geographical areas. We also present a generic resource allocation problem in sensor network which consists of input variables, required output, objectives and constraints. A list of constraints is also tabulated to give an overview of different constraints which are considered while formulating the optimization problem in sensor networks. Keeping in view the multi facet coverage of this article relating to multi-objective optimization, this will open up new avenues of research in the area of multi-objective optimization relating to sensor networks.

1. Introduction

Evolving human needs coupled with the state-of-the art development in various fields, including but not limited to efficient wireless transmission, efficient onboard computational capabilities and miniaturized electromechanical systems have triggered the potential proliferation of sensor networks (SNs) in almost every sphere of human life [1]. Environment monitoring, habitat monitoring, greenhouse monitoring, climate monitoring, home automation [2], industrial automation [3,4], water monitoring [5–7] and personal health monitoring [8] are few promising applications of sensor networks. These networks consist of tiny devices that can sense the environmental data of the surroundings and transmit that data according to predefined set of rules to the central processing unit. These devices or nodes are provided with low computational power, low energy supply and low onboard memory space [9]. Due to these inherent resource constraints, it becomes difficult to design, deploy, operate and manage such networks with reliable and prolonged operation while simultaneously providing the quality of service requirements (QoS) [9,10]. Each of

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the aforementioned problems related to SNs consists of a set of objectives which may or may not conflict with each other [11–13]. Desired scenarios are formulated as multi-objective optimization problems and are solved by using different algorithms [14–16].

A number of real-world problems consist of multiple objectives to be satisfied simultaneously which makes multi-objective optimization (MOO) an undoubtedly very important research area for theorists and engineers [17–19]. These multiple objectives mostly conflict with each other. Hence, there is a less possibility of existence of a global optimal solution contrary to the problems of the single objective optimization [20]. Unlike single objective optimization, in multi-objective optimization there exist multiple optimal solutions and the decision maker selects one of the feasible solutions depending upon the order of preference given to different conflicting objectives. A multiobjective optimization problem can be tackled using different strategies depending on when the decision maker enforces preference on various conflicting objectives [21]. The most commonly used approach is to combine multiple objectives to one figure of merit by assigning different weights to different objectives and then perform single objective optimization algorithm. Weights can be assigned to multiple conflicting objectives through direct assignment, eigenvector method, entropy method and minimal information method etc. Few other commonly used multiobjective handling techniques are Min-Max, Pareto, Ranking, Goals, Preference, Gene, Sub-population, Lexicographic, Phenotype sharing function and Fuzzy [22].

Versatile repository available with the multiobjective optimization makes it suitable to solve many problems related to design, deployment, operation and planning of sensor networks. Various multiobjective optimization techniques and strategies have been used in order to effectively leverage the efficiency of the resource constrained sensor networks [23–25]. For example in [26], the authors have formulated the data aggregation problem as a mixed integer linear optimization problem. They have considered co-channel interference constraints, channel and radio resource constraints to minimize the total transmission power. A multiobjective hybrid optimization algorithm is proposed in [27] to solve the coverage and connectivity problem and to enhance the performance of the SNs with respect to network life time. The authors combined a multiobjective on-demand algorithm employing Genetic Algorithm (GA) and a local on line algorithm.

Literature is brimming with applications of MOO in SNs to solve different optimization problems. This article presents an updated review of the MOO techniques being used to solve different problems relating to design, operation, deployment, placement, planning and management of SNs. It also provides an insight into varying degree of preferences for different conflicting objectives. Hence, it can provide means to configure SNs for different tradeoffs between various performance parameters depending upon the application of the SN. Further organization of the paper is as follows.

Section 2 constitutes highlights of some existing reviews related to the subject. Section 3 depicts a primo on MOO and Section 4 presents classification of MOO. A general resource allocation problem is elaborated in Section 5 and solution approaches are classified in Section 6. Finally Section 7 concludes the paper by reflecting some open challenges.

Table 1
Existing reviews/surveys relating to multi-objective optimization in sensor/sensor networks. EA = Evolutionary Algorithm, TS = Technology Specific Review, Obj.S = Objective function specific review, MOO= Multi-objective optimization.

Reference Number	Review type		Optimization algorithms		
	TS	Obj.S	EA	Heuristic	other
[14]			√		
[15]			√		
[16]					√
[17]			√		
[18]			√		
[19]			√		
[21]			√		
[22]			√		
[23]	√	√			√
[24]	√		√		
[25]	√	√	√		
[29]	√	√		√	
[30]	√	√	√		
[31]	√	√	√		
[32]			√		
[33]					√
[34]			√		
[35]		√	√		
[36]			√		
[37]			√		

2. Existing surveys related to the subject

Highlights of the previous surveys/reviews on the topic are shown in Table 1. It can be inferred that the existing surveys do not encompass the subject completely. For example in [23] the authors have focused on the problem of node placement and surveyed different solution techniques to enhance the performance of the SNs. The authors categorized the existing literature into dynamic and static node placement strategies. They argued that neither of the two techniques in isolation can provide the desired result. Therefore, they suggested to use a mix of static and dynamic schemes. Particle swarm optimization (PSO) techniques have been reviewed in [24] for the optimal deployment, node localization, clustering and data aggregation in wireless SNs. The authors investigated PSO based techniques with respect to their suitability for SNs and suggested how to tailor them according to the peculiar characteristics of sensor nodes. In [25], the authors have categorized various WSN applications and reviewed different energy conservation schemes specifically, their impact on the overall performance of the specific application. They also surveyed some existing techniques based on evolutionary algorithm to achieve various trade-offs between multiple conflicting requirements for prolonging the lifetime of the SNs. Metaheuristic algorithms are getting popular due to their better performance in terms of convergence to the optimality and avoidance from being trapped in local optima [28]. A review is presented in [29] which elaborates application of