Chapter VIII
Multi-Objective Evolutionary Algorithms for Sensor Network Design

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ABSTRACT

Many sensor network design problems are characterized by the need to optimize multiple conflicting objectives. However, existing approaches generally focus on a single objective (ignoring the others), or combine multiple objectives into a single function to be optimized, to facilitate the application of classical optimization algorithms. This restricts their ability and constrains their usefulness to the network designer. A much more appropriate and natural approach is to address multiple objectives simultaneously, applying recently developed multi-objective evolutionary algorithms (MOEAs) in solving sensor network design problems. This chapter describes and illustrates this approach by modeling two sensor network design problems (mobile agent routing and sensor placement), as multi-objective optimization problems, developing the appropriate objective functions and discussing the tradeoffs between them. Simulation results using two recently developed MOEAs, viz., EMOCA (Rajagopalan, Mohan, Mehrotra, & Varshney, 2006) and NSGA-II (Deb, Pratap, Agarwal, & Meyarivan, 2000), show that these MOEAs successfully discover multiple solutions characterizing the tradeoffs between the objectives.

INTRODUCTION

A sensor network is typically composed of a large number of sensor nodes, each of which may carry out simple computations as well as communicate with each other and a *fusion center* (that carries out global inferences) via wired or wireless channels (Shen, Srisathapornphat, & Jaikaeo, 2001; Tilak, Abu-Ghazaleh, & Heinzelman, 2002). Sensor networks can solve difficult monitoring and control problems by exploiting the cooperative effort of multiple sensor nodes, and have been used for myriad applications including military surveillance, homeland security, chemical/biological detection, facility monitoring, reconnaissance and environmental monitoring.

Many sensor network design problems involve the simultaneous consideration of multiple objectives, such as maximizing the lifetime and the information extracted from the network, while minimizing energy consumption, latency and deployment costs. These problems and the associated objective functions are described in Section 2.

The application of *multi-objective optimization* (MOO) techniques in sensor network design problems remains largely unexplored. Existing sensor network design approaches (e.g., Tilak et al. 2002; Yu, Krishnamachari, & Prasanna, 2004) (1) optimize only one objective while treating the others as constraints or (2) convert the multi-objective optimization problem into a single objective optimization problem, that is, they attempt to minimize a weighted sum of the various objective functions, using weights that represent relative "preference strengths." In the absence of a reliable and accurate preference vector, the optimal solution obtained by a weighted approach is highly subjective. The implications of choosing a certain set of preference weights may not be clear to the user until the solution is generated, and a user's intuition cannot be relied on to give weights that accurately correspond to the true preferences of the user. By contrast, an MOO approach, which optimizes all objectives simultaneously and obtains multiple solutions, is more useful for effective decision making. The user can evaluate these solutions based on qualitative higher-level information and make an informed choice, rather than being restricted to a choice implied by prior selection of preference weight values.

Multi-objective evolutionary algorithms simultaneously pursue the search for multiple solutions with varying emphases on different objective functions, and have recently been successfully applied to various MOO problems (Deb 2001; Deb, Pratap, Agarwal, & Meyarivan, 2000; Knowles & Corne, 1999; Zitzler, Laumanns, & Thiele, 2001), outperforming other algorithms such as the weighted sum approach, motivating their application to sensor network design problems, as discussed in the rest of this chapter. In particular, two sensor network design problems (mobile agent routing, and sensor placement) are formulated as MOO problems, and it is shown that they can be solved effectively employing multi-objective evolutionary algorithms.

Section 2 presents a detailed description of sensor network design problems, the main challenges involved, and prior work. Section 3 describes multi-objective evolutionary algorithms used for solving sensor network design problems. Section 4 discusses the mobile agent routing problem, with simulation results. Section 5 describes the sensor placement problem for target detection, along with simulation results. Section 6 discusses postprocessing of solutions obtained by MOEAs. Future research directions and conclusions are presented in Sections 7 and 8 respectively.

BACKGROUND ON SENSOR NETWORK DESIGN

Wireless sensor networks (WSNs) have been used for numerous applications including military surveillance, health monitoring and envi-