A Multi-objective Memetic Algorithm for Relay Node Placement in Wireless Sensor Network

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ABSTRACT

This paper proposes a multi-objective memetic algorithm, namely Mem-NSGA-II, to optimize the relay node placement problem. The network lifetime and the number of relay nodes are two objectives to be optimized. In Mem-NSGA-II, three new local search (LS) operations are designed and incorporated into the fast non-dominated genetic algorithm II (NSGA-II). The first LS operation inserts relay nodes into solutions for extending the network lifetime. The second LS operation aims to reduce the number of relay nodes to save cost. The third LS operation fine-tunes positions of the relay nodes for finding better solutions. The performance of Mem-NSGA-II is compared with a deterministic two-phased method and NSGA-II. Simulation results on five networks reveal that Mem-NSGA-II yields much better performance than the two algorithms.

Categories and Subject Descriptors

I.2.8 [**Artificial Intelligence**]:Problem Solving, Control Methods and search-Heuristic methods; G.1.6 [Numerical Analysis]: Optimization-Global optimization

General Terms

Algorithms, Design, Experimentation.

Keywords

Wireless sensor network, memetic algorithm, relay node placement, multi-objective optimization.

1. INTRODUCTION

A wireless sensor network (WSN) consists of a large number of sensors which monitor a physical environment and communicate in wireless fashion. In many applications of WSNs, sensors are battery-powered and difficult to be recharged. Therefore, designing energy-efficient methods to prolong the network lifetime is a critical issue in the research field of WSNs.

As the energy consumption of communication in WSNs is very costly and it is in proportion to the transmission distance, relay nodes have been utilized in WSNs to reduce the overall transmission distances and prolong the network lifetime. Over the past decades, various methods have been proposed to optimize the relay node placement (RNP) problem, mainly focusing on minimizing the number of relay nodes [1] [2] [3].

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In this paper, we model the RNP problem as a multiple objective optimization (MOP) by considering two objectives: the network lifetime and the number of relay nodes. A novel multi-objective memetic algorithm, namely Mem-NSGA-II, is proposed to provide decision makers with enough representative alternative solutions. Three local search operators are designed and incorporated into the fast non-dominated genetic algorithm II (NSGA-II) [4] to search for high-quality alternative solutions. Five different networks are used to investigate the performance of Mem-NSGA-II. The simulation results reveal that the proposed Mem-NSGA-II outperforms the deterministic two-phased placement strategy [3] and the NSGA-II [4].

2. PROBLEM DEFINITION

We consider a heterogeneous WSN with three types of devices, i.e., sensor nodes (SNs), relay nodes (RNs) and a base station (BS). The positions of SNs are known in advance. The transmission distances of all SNs are set to be R_s. Each SN sends packets to its neighboring RNs (or the BS) via one hop and it does not relay traffic for other nodes. The RNs are used to collect packets from sensors and to forward packets to the BS via one or multiple hops. The transmission range of a RN is R_c. The BS is located at the center of the monitoring region. The minimum transmission energy (MTE) routing strategy and the communication power consumption model used in [5] are utilized to compute the lifetime of the network. The multi-objective RNP problem is defined as follows:

"*Given a BS and a set of predetermined SNs, determine the number and the positions of RNs, so that the number of RNs can be minimized and the network lifetime can be maximized.*"

3. MEM-NSGA-II FOR RNP IN WSNS

The Mem-NSGA-II uses a set of 2-D coordination to represent a solution. Each individual contains D vectors, with each vector representing the position of a relay node. Before evaluating the fitness of a solution, a repair operation adds relay nodes to ensure the connective constraint is satisfied. The general algorithm framework is described as follows.

Step 1 – Initialization: This step generates an initial population.

Step 2 – Genetic operations: This step utilizes the three genetic operators (i.e., selection, crossover and mutation) to generate N new individuals.

Step 3 –Add node operation: This operation finds solutions with longer lifetime by adding RNs into some promising solutions. The main idea is to reduce the transmission distance of the critical node which has the shortest lifetime by adding new relay nodes in the network.

Step 4 –Delete node operation: The purpose of this operation is to find feasible solutions with fewer RNs. Candidate solutions are selected from an extra set ***B*** which stores the best *N* solutions having the least relay nodes. Then some relay nodes in the selected solution are randomly deleted.

Step 5 – Local refinement operation: This operation is used to fine-tune positions of all RNs, so that the network lifetime can be further prolonged. When fine-tuning the position of an RN, its lifetime and that of its predecessor RN and successor RN are computed to determine the moving direction.

Step 6 – Updating operation: First, the fast non-dominated sorting method and the crowding distance in NSGA-II are utilized to select the best *N* individuals to form the new population. Then the extra set ***B*** is formed by selecting the best *N* individuals in terms of the number of RNs.

There is a repetition from *Step2* to *Step6* until reaching the maximum number of evaluations.

4. SIMULATIONS AND COMPARISONS

Table I Parameter Settings

Algorithms	Parameter values
NSGA-II	$N = 100$, $px = 0.8$, $pm = 0.01$, $MAX\text{-}FES = 5.0\times10^4$
Mem-NSGA-II	$N = 100$, $px = 0.8$, $pm = 0.01$, $MAX\text{-}FES = 5.0\times10^4$ *fine-turn step size = 0.02*, *Maximum number of RNs to be deleted in Step4 = 2*

In this section, we perform simulations on five networks with 50 SNs. All SNs are randomly deployed in a 100m×100m monitoring region. In each test case, the initial energy of each SN and each RN is respectively set to be 20J and 100J. The energy consumption for receiving and sensing one bit information is set to be 50nJ/bit, other network parameters are set to be E_{elec} = 50nJ/bit and ε_{amp} = 100pJ/bit/m2 (referred to [5] for the meanings of parameters). The data rate generated by each sensor is 1kb/round (round is the time unit of each sensor transmitting data to the BS). The communication range of each SN and that of each RN are respectively set to be 10m and 20m. The parameter settings are listed in Table I. Both NSGA-II and Mem-NSGA-II are run for 30 times on each test case.

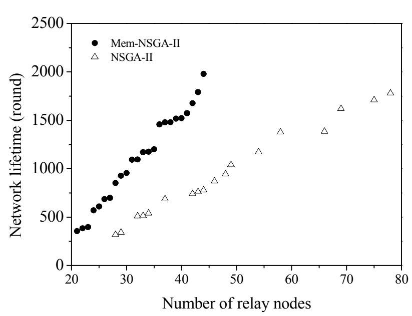

Figure 1. Alternative solutions found by NSGA-II and Mem-NSGA-II.

Fig. 1 shows the alternative solutions found by NSGA-II and Mem-NSGA-II in a single run, on a 50-sensor network. It can be observed that, both algorithms provide multiple alternative solutions. However, with the same number of RNs, the networks found by Mem-NSGA-II have much longer lifetimes than those found by NSGA-II. Table II shows the comparison results of minimizing the number of RNs. It can be observed that Mem-NSGA-II significantly outperforms the two-phased method and NSGA-II on all test cases, in the sense of minimizing the number of RNs.

Table II Comparison results of minimizing the number of RNs

ID	*N*	*Two-phased*		*NSGA-II*		*Mem-NSGA-II*	
		n	*t*	*n*	*t*	*n*	*t*
1	50	25	126	28.57	298.20	**21.13**	278.57
2	50	25	272	26.03	263.23	**19.83**	272.80
3	50	27	124	30.70	274.67	**23.23**	309.47
4	50	24	267	30.33	270.83	**22.53**	259.03
5	50	25	87	31.67	292.10	**23.37**	224.43

(*ID*, *N*, *n*, and *t* respectively represent the network index, the number of SNs, the number of RNs and the network lifetime)

5. CONCLUSIONS

In this paper, the RNP problem is formulated as a multi-objective optimization problem. A novel multi-objective memetic algorithm (Mem-NSGA-II) is proposed for finding multiple alternative solutions that provide different trade-offs between the cost and lifetime of a WSN. The proposed Mem-NSGA-II is a hybridization of the fast non-dominated genetic algorithm II (NSGA-II) and three problem-specific local search operations. Simulation results on five different networks demonstrate that the proposed Mem-NSGA-II yields much better performance than the deterministic two-phased method and the NSGA-II.

6. ACKNOWLEDGMENTS

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