Reliable Wireless Multimedia Sensor Network Design for Surveillance with Hybrid Metaheuristics

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1 Introduction

Wireless Multimedia Sensor Networks (WMSNs) are the networks of wirelessly interconnected devices that allow retrieving video and audio streams, still images, and scalar sensor data from the environment [1]. In this paper, a new information gathering reliability of the WMSNs integrating connectivity and coverage with a deployment plan for the surveillance of opponent territories is studied. The information gathering reliability is maximized with a total budget constraint. Since the placement, coverage and reliability problems have NP-hard complexity, two hybrid metaheuristics (a Hybrid Simulated Annealing (HSA) and a Hybrid Genetic Algorithm (HGA)) are proposed. A Branch & Bound (B&B) method is incorporated into the metaheuristics to find the exact orientations of the sensors.

2 The Problem Statement and The Mathematical Model

The terrain (Ter) is assumed as 2-D, and it is represented as a regular point based surface. It can be considered as a clustering method to reduce complexity. The WMSN aims to make surveillance of predefined targets on Ter. Each sensor collects and sends the data to the base station (b) via other sensors or relay nodes.

A candidate point $i \in \mathcal{I}$ (a set of candidate points), for sensors and relay nodes on Ter has the following properties; x coordinate (x_i), y coordinate (y_i), safety weight (sw_i, [0-1]) and occlusion weight (ow_i, [0-1]). The sw_i can be defined as the probability of operating a node safely and the ow_i represents the occlusion density of the point.

Additionally, a point $k \in \mathcal{T}$ (a set of targets), representing a target on Ter has importance weight (iw_k, [0-1]). If iw_k is 1, it means the point is at the top priority to be covered. The summary of the iw_k of all the points on the Ter is the total data that can be gathered.

The properties of sensor $j \in \mathcal{S}$ (a set of sensors) are deployment point (p_j), depth of view (d_j), viewing angle (v_j), heading angle (h_j), cost (c_j), communication range (r_j) and hardware reliability (rel_j, [0-1]). Correspondingly, a relay node $l \in \mathcal{R}$ (a set of relay nodes) has cost (c_l), communication range (r_l) and hardware reliability (rel_l, [0-1]).

The coverage on a target k by a sensor j is formulated in Equation (1). The $maxocc_{ik}$ is the maximum ow_i on the line between the node i and target k. $Cone_{ijk}$ is 1, if i is in the view cone of sensor j; otherwise, it is 0. The node connectivity is based on the Euclidian distance. If the distance between two nodes is less than a certain communication range (r_j or r_l) the nodes are assumed as connected.

$$Cov_{jk} = (1 - maxocc_{ik}) * Cone_{ijk} \tag{1}$$

In this paper, two new reliability definitions are made for the nodes in WMSNs. The first reliability definition represents the function of a sensor j on i that is covering target k presented in Equation (2). The second definition presented in Equation (3) involves the function of a relay node l on i. Equation (2) and (3) are used in the reliability calculation of the designed network as the information gathering or transmitting reliabilities of the nodes.

$$Rel_{ijk} = rel_j * sw_i * (1 - maxocc_{ik}) \tag{2}$$

$$Rel_{il} = rel_l * sw_i \tag{3}$$

Consequently, the new WMSN reliability calculation integrating connectivity and coverage is presented below in the mathematical model as the objective function. The reliability is defined as $RelIG(S, R, Ter)$ and it represents the gathered information from every covered target k by sensors (S) and delivered via relay nodes (R) and S to the b on Ter over the total information $(\sum_{k \in T} iw_k)$ on Ter. For each target k covered by $s' \in S$, the $r' \in R$ and $s' \in S$ are connecting s' to the b on the Ter. Thus in the model, there are network reliability calculations $(\sum_{k \in T} \widehat{Rel}(s', r', b, k))$ of each covered target k by s'. Here, the exact calculation of network reliability is NP-hard, therefore a Monte Carlo method is used to estimate $(\widehat{Rel})$. Total budget (TB) is a constraint in the model. x_{ijm} is 1 if camera j has orientation m on point i, else it is 0. x_{il} is 1 if relay node l is on point i, else it is 0.

$$\max RelIG(S, R, Ter) = \frac{\sum_{k \in T} \widehat{Rel}(s', r', b, k) * iw_k}{\sum_{k \in T} iw_k} \tag{4}$$

$s.t.$

$$\sum_{j \in S} \sum_{m \in O} x_{ijm} + \sum_{l \in R} x_{il} \leq 1, \ \forall i \in I \tag{5}$$

$$\sum_{i \in I} \left(c_j * \sum_{j \in S} \sum_{m \in O} x_{ijm} + c_l * \sum_{l \in R} x_{il} \right) \leq TB \tag{6}$$

$$x_{ij}, x_{il} \in \{0, 1\}; \ \forall i \in I; \ \forall j \in S; \ \forall m \in O; \ \forall l \in R \tag{7}$$

3 The Methodology

As mentioned before, since the defined problem has NP-hard nature, two hybrid metaheuristics (a HSA and a HGA) are proposed. A B&B method is incorporated into the metaheuristics to find the exact orientations (O) of the sensors to increase the network reliability. The hybrid metaheuristics are designed special to the problem. For instance, HGA has reliability-based crossover operator. The effectiveness of the proposed approaches is presented by numerical experiments and they compared with the simple SA and GA.

4 The Experimental Design and The Results

The parameters of the algorithms are tuned. Varied types of problem sets are generated for comparison. Different size of terrains with several target, sensor and relay properties are tested. The effect of total budget amount is also analyzed. The results for a sample problem set which has 1 b and 5 targets on a 10x10 Ter with different sw and ow are presented below (Table 1). The total budget is 100. The sensors have d=2, v=90, c=10, r=2 and rel=0.9. The relay nodes have r=3, c=5 and rel=0.9. 10 runs are made for the algorithms.

Table 1. Results for a sample problem set

	SA	GA	HSA	HGA
Best	0.859	0.859	0.873	0.876
Average	0.812	0.796	0.814	0.843
Worst	0.722	0.740	0.719	0.804

References

1. Akyildiz, I.F., Melodia, T., and Chowdhury, K.R. (2007). A Survey on Wireless Multimedia Sensor Networks, *ComputerNetworks*, 51, 921-960.