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Keywords : *Internet of Things, Wireless Sensor Networks Deployment, Multi-Objective Combinatorial Optimization, Linear Programming, Coverage, Connectivity, Latency, Energy Consumption*

1 Introduction

The recent rapid proliferation of the Internet-of-Things (IoT) paradigm has resulted in numerous new applications and online services. The smart car park is one good example of how wireless sensor developments can be used in real-world practical applications. Our present research focuses on the optimization of the Wireless Sensor Network (WSN) deployment for a fire surveillance system in smart car parks. The deployed WSN consists of two types of nodes, namely Sensor Nodes (SN) and Relay Nodes (RN), installed inside the smart car park. SNs are dedicated to cover targets (i.e., vehicles) while RNs relay alert messages generated by the SNs when the latter detect a fire up to the sink node installed in the middle of the WSN.

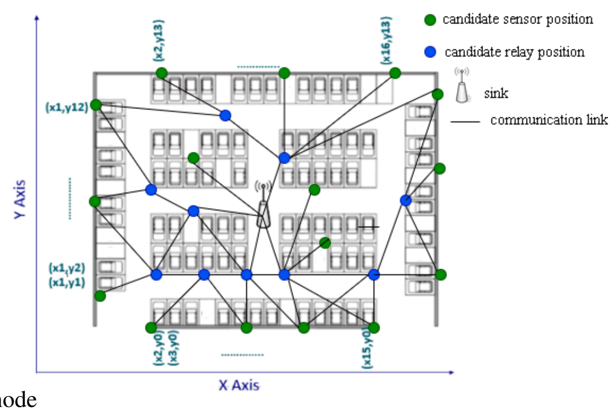
In general, existing research on the deployment of WSNs has focused on the successive placement of SNs and then RNs [1][2][3], or the simultaneous placement of both SNs and RNs, using a mono-objective function [4] which provides only one solution, aiming to minimize the deployment cost while maintaining low network delay and energy consumption.

In this study, we propose a simultaneous placement of both SNs and RNs using a multi-objective solution, which offers a better alternative to the current WSN deployment solutions, as revealed by our obtained performance results. We formulate our WSN deployment problem as a Multi-Objective Binary Integer Linear Programming (MOBILP) in order to minimize the number of SNs, RNs and the diameter [1] of the WSN, while ensuring coverage and connectivity constraints.

2 Problem definition

We consider the WSN as a graph consisting of the union of sets of n Candidate Sensor Positions (CSP), m Candidate Relay Positions (CRP) and one sink V_1 as shown in Figure 1. There is a set of targets T, and each sensor i has a list $s_i \in T$ of targets that can monitor them. The objective is to find, the optimal set V_s^{opt} of SNs and the optimal set V_r^{opt} of RNs, such that $\bigcup_{i \in V_s^{opt}} s_i = T$, and each sensor node must be connected to the

FIG. 1 – The deployed WSN in the smart car park



1. Maximum distance from the sensor nodes to the sink node

sink, even directly or through a path composed only of relay nodes (two-tiered architecture), in order to minimize $|V_s^{opt}|$, $|V_r^{opt}|$ and the maximum distance of the shortest paths (in terms of hop count) between all the sensor nodes and the sink node ($max_{i \in V_s^{opt}}\{dist_{i,V_1}\}$).

3 Problem formulation

In this study, we propose a MOBILP to solve WSN deployment problem. The binary decision variables used in our MOBILP approach are x_i^k, r_i^k and y_k, which means respectively, if a CSP i located k hops from the sink is selected or not, if a CRP i located k hops from the sink is selected or not, and whether there is a k hops length path from RN to the sink or not. Therefore, our MOBILP is as follows :

$$\min \left\{ F1 = \sum_{i \in V_s} \sum_{k=1}^{K+1} x_i^k, F2 = \sum_{i \in V_r} \sum_{k=1}^{K} r_i^k, F3 = \sum_{k=1}^{K} y_k \right\}$$

$$\sum_{k=1}^{K+1} \sum_{i \in V_s^t} x_i^k \geq 1 \qquad \forall t \in T \qquad (1)$$

$$x_i^k \leq \sum_{j \in V_i^r} r_j^{k-1} \quad \forall i \in V_s \backslash V^1, \forall k = 2 \dots K+1 \quad (2)$$

$$r_i^k \leq \sum_{j \in V_i^r} r_j^{k-1} \quad \forall i \in V_r \backslash V^1, \forall k = 2 \dots K \quad (3)$$

$$y_k \geq r_i^k \quad i \in V_r, k = 1 \dots K \qquad (4)$$

where :

V_s is the set of CSPs, V_r is the set of CRPs, T is the set of targets, V_s^t is the set of CSPs which cover the target $t \in T$, V_i^r is the set of CRPs $\cup$ $\{sink\}$ which are neighbors with CSPs or CRPs, V^1 is the set of CSPs and CRPs which are neighbors with the sink node, and K is the maximum number of hop-count allowed initially.

4 Results

In this work, we have solved our MOBILP using "ϵ-Constraint algorithm" in which we call Gurobi solver. We have conducted extensive tests on three scenarios. The first one is completely random. The two others scenarios are close to reality, with the first one having 60% of the targets distributed in the lower left quarter near the smart car park entrance and 40% distributed arbitrarily in the three other quarters, while the second having 60% of the targets distributed in the three first columns near the smart car park entrance. We have compared MOBILP to the sequential approach which places SNs to meet coverage, then RNs to guarantee connectivity [1][2][3], and to the simultaneous approach which simultaneously deploys SNs and RNs [4] to fulfill coverage and connectivity. It is noteworthy that the second approach uses the sum of objectives (equal weights) to build the multi-objective function, leading to a single solution. MOBILP explores more of the research space than the first approach, which eventually increases the chance to find more efficient solutions. Furthermore, since MOBILP is a multi-objective solution, it provides a set of solutions that includes the second approach's single solution. Therefore, our MOBILP offers better solutions and greater flexibility in choosing the best compromise between conflicting objectives.

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