Wireless Sensor Network Clustering for UAV-based Data Gathering

Celia Yasmine Tazibt *, Mustapha Bekhti†, Tounsia Djamah* Nadjib Achir†, and Khaled Boussetta†
*LARI laboratory, Mouloud Mammeri University of Tizi-Ouzou
B.P N° 17 RP – Tizi–Ouzou, Algeria
†L2TI Laboratory, Université Paris 13, Sorbonne Paris Cité
99 Avenue J-B Clément, 93430 Villetaneuse, France
Email: {bekhti.mustapha,nadjib.achir,khaled.boussetta}@univ-paris13.fr

***Abstract*—With the ongoing system miniaturization, sensors capabilities and cost reduction, a new opportunities are created to accomplish data reduction and sensors fusion on small systems. This is the case for Unmanned Aerial Vehicles and the interest that they generate in applying this technology in remote sensing and data gathering in a wide wireless network. In another hand, it is clear that the use of mobile robots in a such network reduces the energy consumption for the static nodes, while forwarding data to a sink node and therefore extends the lifetime of the network. In this paper we attempt to demonstrate the advantage of integrating small scale drone in a terrestrial wireless sensor network, for environmental monitoring and data gathering.**

I. Introduction

In this paper, we are interested in the use of the drones for data gathering in wireless sensor networks. In fact compared to the classical data collecting schemes where all nodes forward data to a sink node which requires both a reliable end-to-end link between the sink and the sensors and an important energy consumed by the sensors to forward data, the use of a mobile data collector offers a better energy saving for all other sensors and therefore extend the network lifetime. This gain is more important where few sensor nodes are deployed in a wide network. In almost all wireless sensor networks, the sink is considered as a crucial entity in terms of computational capacity, communication capabilitie and notably the energy consumption. This is why the sink node is usually attached to a mobile entity such a ground vehicle, which can move inside the sensor field for data collection and gathering. Thus, considerable energy saving can be obtained by using a mobile sink in sensors field. In this frame [4] identified several potential advantages of sink mobility in the sensor field, such as sensor lifetime enhancement and coverage. In addition, the use of drones in such situation seems to be more efficient compared to the ground mobile data collectors where obstacles and hilly terrain could inhibit the achievement of the mission. UAVs (Unmanned Aerial Vehicles) can quickly obtain an accurate data over large areas that are hard to access by ground means.

To address this issue, recent research investigated the use of UAVs as Data Collectors in large scale Wireless Sensor Networks [5] [7]. In addition, different studies were carried out in the sake of finding the optimal paths of a mobile node to collect data. The best known approach for path planning is to use the Traveling Salesman formalization of the problem (TSP) [6]. To deal with energy and to avoid the formation of hole phenomena among a wireless network, [3] presented a solution based on hybrid unconstrained movement pattern for a single mobile sink with the aim of finding the near optimal traveling tour based on weighted rendez-vous planning. This paper presents a framework for UAV gathering data mission that adapts multi objective decision in generating the UAV path. Such mission involves finding a subset of nodes acting as cluster heads within the ground wireless sensor network and which the drone can use as a waypoint for collecting data.

The remainder of this paper is organized as follows. Section II describes the system and the platform used for the drones tracking and data gathering evaluation. The proposed approach and the obtained results are then evaluated in different scenarios. The results are reported in Section III. Finally, Section IV conclude the paper.

II. Problem Formulation

In this section, we outline the different phases involved in reporting data in a wireless sensor network. Without loss of generality, we consider an area of interest A where a set of ground wireless sensor nodes S are deployed and a single drone D acting as a mobile sink. Basically, our objective is to use the drone to retrieve all the data collected by the sensors. One first approach is to fly over all the sensors to retrieve the data. This approach can induce a significant path length that the drone should follow. However, it has a valuable advantage, which is a reduced energy cost for the sensor network. Indeed, each sensor has to send its data directly to the drone, when the latter flies over the sensor. No routing protocol is required at the network. However, since the flight time of the drone is also limited due to battery constraints, we also should limit the tour length of the drone. In this case, the second approach is to elect a specific sensor as sink and all the sensors have to send their data to that sink. Thus, the drone can retrieve all the data from one specific node acting as cluster head. Unfortunately, even if this approach preserves the drone's energy by highly reducing its flight time, it may increase the energy consumption of the network. Indeed, the data must be routed through the sensor network to the sink. This routing process increases the number of packets in the network, and consequently the energy spent

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by the sensors, and more specifically the sensors near to the sink since they concentrate all the traffic. Generally, increasing the number of sensor nodes acting as cluster head leads to increase the energy consumed by the drone and decrease the energy consumed by the network, and vice-versa. In this paper, two objectives are fixed, namely:

1) to minimize the energy consumed by the sensors.
2) to minimize the drone's energy consumption by ensuring that the path the drone should follow using the cluster heads as waypoints has a minimum length.

In order to resolve this issue we start by splitting the problem into two sub-problems. First, we have to select the sensors that have to act as cluster heads and then compute the path that the drone should follow to cover these cluster heads. For the selection of the cluster head we use a parameter , called h, representing the maximum number of hops allowed between a sensor and the cluster head. Basically, if we decrease the maximum number of hops than we increase the number of clusters. On the other hand, if we increase the maximum number of hops we decrease the number of clusters.

In order to compute the path of the drone to cover all cluster heads, we propose to use the 2-opt heuristic. 2-opt heuristic is a simple local search algorithm for solving the well-known traveling salesman problem.

A. Wireless Sensor Network Clustering

As mentioned above, our first objective is to deploy the minimum number of cluster heads, in such a way that for each sensor s there is a cluster head c, where the distance in terms of the minimum number of hops to reach s from c is less than or equal to h. This problem can be formulated as a *set covering problem* as following:

$$\begin{aligned} \text{minimize} \quad & \sum_{j \in S} x_j \\ \text{subject to:} \quad & \sum_{j \in S} a_{ij} x_j \geq 1, \ \forall i \in S \\ & i \neq j, \\ & x_j \in \{0,1\}, \ j \in S \end{aligned} \tag{1}$$

where x_j and a_{ij} are binary variables. Basically, the decision variable x_j, $j \in S$ indicates whether a sensor j is acting as a cluster head or not. Finally, each variable a_{ij}, $\forall i, j \in S$ is equal to 1 if the sensor i is within the h hop coverage area of a cluster head j. In order to compute the distance in terms of hops count between a sensor i and a cluster head j, we apply the shortest path strategy for the undirected graph obtained by the sensors as vertices and the possibility of a communication link between sensors as edges. More precisely, we consider the existence of a link between two nodes, one of which may be the cluster head, if and only if both nodes are within the transmission range of each other.

Based on this formulation, we can derive the optimal set CH^* of cluster heads that should be considered in order to guarantee that each cluster head can be reached by a sensor with a maximum of h hops. Thereafter, we can derive the underlying network as an undirected graph $G = (V, E)$, where each node is represented by a vertex $v \in V$ (where V = S) and E is the set of undirected edges denoting the communication links. From the previous graph G we constitute a new graph $G' = (V', E')$, by adding a new virtual vertex representing a single super cluster head which is directly connected, with unweighted edges, to all the cluster heads belonging to the set CH^*. Thus, $V' = V \cup \{ch'\}$ and $E' = E \cup \{(n, ch') | \forall n \in CH^*\}$. The main idea behind this graph transformation is to be able to derive the shortest path routing strategy adopted in this paper by applying for example the Minimum Spanning Tree algorithm, that requires a single source. Since we fix the same cost for all the edges, computing the shortest path from each sensor to the closest cluster head leads to compute the shortest path from the same sensor to the super cluster head. Finally, we define the set P as the set of shortest paths for all v in $\{V - CH^*\}$. We also define $P(v)$ as the subsets of P where the node v is present.

B. Wireless Sensors Energy Consumption Model

In most of existing works, the wireless sensor network lifetime can be defined as the time span from the initial deployment until the time where the network is considered as unable to operate as it was initially designed for. In this work, we consider that the wireless sensor network is considered as inoperative when the first sensor node has exhausted all its energy. In addition to the last assumption, and since we are interested in a reporting application we define the energy consumption at each node as the sum of the energy consumed for each one of the two following cases:

1) Packet reporting: We consider that the energy consumed by a sensor for a periodic packet reporting is equal to the amount of energy used for the event sampling process and the transmission of the data related to that sampled event. Basically, for a sensor v, the reporting consumed energy is equal to: $E_r(v) = E_s + E_{tx}(l)$, where E_s is the energy consumed for event detection and E_{tx} is the energy consumed due to the packet transmission. The later represents the total amount of time spent in transmit mode and depend on the number of sent packets, and the time required to transmit these packets. For sake of simplicity, we assume in the following that amount of energy used for sampling is negligible compared to the energy required for packet transmission.
2) Packet forwarding: We can divide the packet forwarding into two distinct steps. Basically, a node starts by receiving a packet, and after identifying the next hop, starts transmitting that packet to that next hop. In this case, the energy consumed by the node is equal to the energy spent for receiving the packet plus the energy spent for sending it. Formally, $E_f(v)$ can be formulated as follows: $E_f(v) = \sum_{i=1}^{|P(v)|-1} (E_{rx}(l) + E_{tx}(l))$, where $E_{rx}(l)$ corresponds to the energy consumed by a sensor for receiving a packet of size l. As defined in the last

section, $P(v)$ is the subsets of P, where the sensor v is present.

C. Drone Path Planning

Once we select the cluster heads, we have to compute the path that the drone should follow in order to collect the data from these cluster heads. In this paper, we propose to use the 2-opt heuristic to compute this path. This heuristic is a local search algorithm designed to resolve the TSP. Basically, this algorithm starts with a feasible solution and iteratively looks for an improved solution by removing two edges and replacing them with two different edges that reconnect the path and creating a new and shorter tour.

III. RESULTS

In this section we evaluate the proposed model and our aim is to find the best number of clusters that should be selected in order to fit the maximum flight capability for the drone. In the following, we study the impact of varying h value on the energy consumption of the sensor network and the drone. We have conducted some tests considering an area of $100m \times 100m$. They're after, we randomly deployed 200 sensors using the Random Poisson Point Process in our sensing area. We also considered that all the sensors have the same communication range capability and the same initial energy (i.e. capacity for the battery). For that, we use the energy values of the `cc2420` family [2]. To solve the cluster head election optimization problem we used the `Cplex` solver. Since the complexity of our problem is related only to the number of sensors deployed within the area and since we are considering the constraint that each sensor has to reach at least one cluster head, then we were able to solve this optimization problem for relatively large number of sensors. We use the characteristics of the DJI Phantom 3 Standard Advanced as reference to compute the energy consumed bu the drone to collect the data [1].

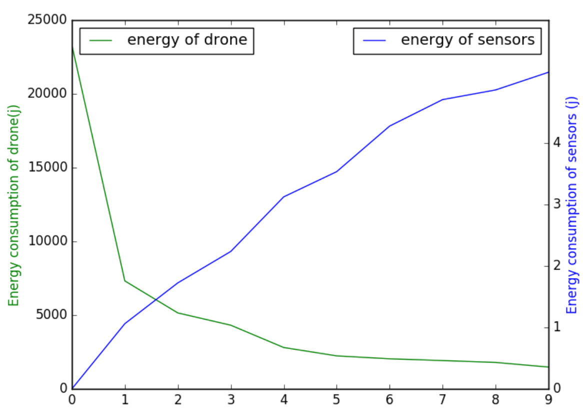

Fig. 1: Energy consumption of the drone and energy consumption of the sensors vs number of maximum hops (h)

In order to evaluate the energy consumption of the network, we studied its behavior by considering the energy consumed when sending a single packet of size 26 bytes. We have thus varied the parameter h from 0 to 9 to observe its impact on the energy consumed by the sensors and the drone. The graph in Fig 1 shows the evolution of the average energy consumption by both the sensor network and the UAV. We can see that the value of h strongly influences the consumption of the sensors, which increases when we increase the number of hops authorized in a cluster. This implies that the number of nodes that can be attached to a cluster head increases, which also increase the data exchanged. At the same time the energy consumed by the drone is also influenced by the h. This is also depicted in this graph by a decrease of the consumed energy when we increase h. In fact, when the value of h is equal to 0, the consumption of the drone is at the maximum level because the drone needs to travel a long distance in order to collect the data from all the sensors. In conclusion, the maximum number of hops can be chosen according to different requirements. For example, if the drone have an important amount of energy and the sensors have a small battery, we can then use a small value for h. On the contrary, we need to increase h.

IV. CONCLUSION

In this paper, we preset a simple yet efficient model in order to collect data from a large number of sensors using drones. It is clear that because of the large number of sensors that we are considering, it is not possible for the drone to fly over all the sensors. In this case, we propose to elect a subset of nodes that have to act as cluster heads. The cluster heads are in charge of collecting the data from the sensors. Theyre after, the drone has only to collect the data from the cluster heads following a tour that cover all cluster heads. In order to act on the number of cluster heads, we consider the maximum number of hops allowed to any sensor to reach a cluster heads as parameters. By decreasing the maximum hops, we are able to save energy of the sensor network against the drone and vice-versa. The obtained results show that we could obtain a good trade off by acting only on the maximum hops.

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