

Opportunistic Computational Offloading System for Clusters of Drones

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Abstract— Providing many beneficial characteristics, Unmanned Aerial Vehicles (UAVs) have become extremely popular in terms of their utilization in everyday life and military system. As they have bigger and more advanced tasks as time goes by, clusters of small UAVs are preferred rather than one single large UAV since they offer bigger coverage area, higher flexibility, and even more reliability. However, the drone system has limited computing power and energy resource which makes it a challenge how to utilize this system to have a long operation time. In this paper, we propose an *opportunistic computational offloading* system which borrows computing power from other drones cluster to help finishing tasks on a specified cluster. When there is a drone cluster having a lot of computing tasks exists with another cluster in the communication range that has enough computing resources or in the idle state, our proposed scheme will make a cluster head to opportunistically decide to do offloading or not by considering various costs. The proposed scheme aims to increase the drone's lifetime and also to shorten the response time.

Keywords— Cluster, Computational Offloading, Drone, Multiple UAVs, Wireless Communication

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) or drones have become popular in both military and civilian applications. This popularity of utilizing drones is because it has lower operation cost and more safety for humans if compared to the traditional manned craft. UAVs can be used in many areas, including transport management, post mail delivery, smart cities, safety monitoring, and disaster management [1]. More, in military applications, drones are utilized for surveillance [2] as well as for engaging with the enemy [3].

Recently, the deployment of multiple small UAVs as a swarm to complete various tasks has gained more spotlights as they improve the effectiveness of current single UAV system and also provide cheaper cost. Employing a group of small UAVs, rather than a single large UAV, presents many advantages, such as the opportunity of guaranteeing a reliable ad-hoc network, improving the operation performance, extending the mission coverage [4], and even reducing the possibility to be detected in such a reconnaissance mission.

While the UAVs' tasks are growing larger and more complex day after day, their computing power and energy resource are very limited, even for drone cluster. The problem of insufficient energy and computing resources can be

addressed using computational offloading [5] to a ground control station (GCS) which has unlimited energy and higher computation power or even to the drones' neighbours which have enough resources to process the given task.

As cluster of drones provide different kind of services, vary from mail delivery system which has relatively small computing task to surveillance system which needs large computing power. In such case, cluster with higher computation service is capable of utilizing the opportunity of borrowing other clusters' resources for processing its tasks.

In this paper, we propose the feasibility of applying computational offloading mechanism for clusters of drones. Specifically, we propose an opportunistic and adaptive computational offloading scheme between drone clusters. Cluster head will detect if there are any other cluster heads near it and will communicate if those clusters have available resources or not. Then, the cluster head will estimate the response time for doing the computational offloading and processing the given task (e.g. image processing) through computing power, size of task, bandwidth, and data rate of wireless network. From the estimated result, the cluster head will decide if it is better to do the task alone or to share the load to the other cluster. The contribution of this paper is the design of computational offloading scheme between clusters of drones which aims for increasing the drones' operation time and reducing the response time. Because the deployment of clusters of drones is becoming more popular these days, more discussions and works regarding drone cluster are needed to improve such a system in the future.

The rest of the paper is structured as follows. We summarize the motivation and related work in Section 2. Then, we present our opportunistic computational offloading in Section 3. Last but not least, we conclude this work in Section 4.

II. MOTIVATION AND RELATED WORK

A. Motivation

More clusters of drones are being utilized these days and they serve various kinds of application services. If we assume that as the work become more complex in the near future, people would likely to implement more clusters of drones rather than a single UAV, works and discussions about inter-

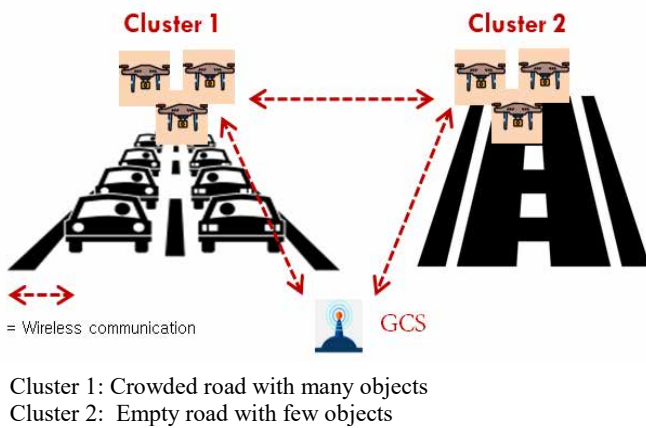


Figure 1. Drone clusters with same tasks, but different environment

UAV cluster communication will become a significant issue. Because our proposed offloading scheme aims for inter-UAV clusters system, we define use case scenario where the UAV cluster-to-UAV cluster offloading scheme might be applied in the real situation.

On Fig. 1, it is shown the scenario when drone clusters have same service, but different environment. Given that two clusters of drones work for surveillance system on two different areas with the same workload. One cluster works on a harsh environment (high populated road) with many noise objects; meanwhile another cluster operates on a convenient environment (e.g. empty road). By considering the condition of the environment, the first cluster will have relatively a harder work and need more time to complete its tasks. On the other hand, the other cluster will finish its task peacefully without additional burden. Considering those environment conditions, the cluster which is deployed in the empty road will complete its work first because fewer noises are produced on there. Therefore, it will likely to have unused computing power and resources that could be borrowed by the other cluster. In other word, the first cluster can use our proposed scheme to offload part of its tasks to the second cluster.

B. Related Work

Computational offloading concept has been studied many years. Authors in [6] investigate the possibility of handing off computing tasks to other devices via communication interfaces. However, drones have a dynamic environment so that it is harder to predict the response time of drones rather than the static one.

The possibility of doing offloading scheme in UAVs system itself has been developed recently. Authors in [7] design a system for computational offloading from the surveillance drone to the GCS using ACODS architecture. By considering computing cost, networking cost, and I/O cost, the system is comparing the delay needed to execute tasks between being done in a GCS or in the UAV itself. In [8], the authors propose the computational offloading scheme among UAVs which carry out internet of things (IoT) services. The goals are to enhance UAV's lifetime and reduce the response time. Authors in [9] propose to offload UAV-based internet of

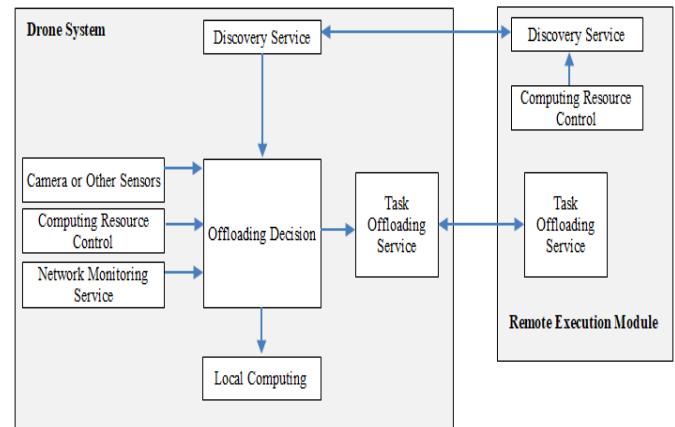


Figure 2. Opportunistic Computational Offloading System Architecture

things (IoT) platform's workload to a mobile edge computing (MEC) node in a crowd surveillance use case. The goal is to reduce the processing time of recognition and detection. However, neither of these works addresses the problem of implementing the offloading scheme among clusters of drones.

III. OPPORTUNISTIC COMPUTATIONAL OFFLOADING

A. Cluster Discovery Scheme

For achieving an opportunistic offloading scheme, drone clusters need to discover other clusters near them. In the proposed idea, fundamental discovery scheme is used. First, cluster head will broadcast a 'hello' message indicating their presence and available resources at a certain periodic time. Then, any cluster which wants to do task offloading scheme will be able to detect this cluster's presence through discovery service in the system. Next, that local cluster may send an offloading request to a desired cluster head. By utilizing such method, drone clusters are capable of recognizing their environment situation and may exploit the opportunity to offload their tasks.

B. Computational Offloading Decision Module

After discovery process, local cluster head will learn nearby situation whether there exist other group of drones or not. Then, it can proceed to the offloading decision stage which will give a final decision to process the tasks locally or to do offloading. Various inputs are considered for the offloading decision module. Discovery service will provide information such as other drone clusters' presence and also their computing resources. Camera or other sensors would provide the tasks to the drone system. Computing resource control module brings knowledge about vacant computing power of the cluster by monitoring the computing resource usage of each member in the group. Network condition information between the cluster head and the members would be provided in the network monitoring service.

For making an offloading decision, the proposed scheme takes benefits of estimated elapsed time (locally or remotely). By comparing whether local computing is faster than offloading computing, the offloading decision engine would give out a final conclusion. In this system, estimating the

response time is done with consideration of the communication delay (t_{comm}) and computing delay (t_{comp}). Let T is the estimated time consumed for finishing all tasks.

$$T = t_{comp} + t_{comm}. \quad (1)$$

Computation delay can be calculated by accumulating all computational power of each member in the cluster. Computational power is generated by multiplying the fully utilized CPU computing time of one byte of task ($t_{optimized}$) with the percentage of the available CPU resource (r_{avail}). CPU resource is usually partially used for maintaining the position of the drone in the air or other software task; hence r_{avail} represents the idle computing resource of the CPU. Given N is the total number of drones in a cluster and $work_i$ is the work which is assigned to a member i . Therefore, the computation delay (t_{comp}) can be written as (2).

$$t_{comp} = \sum_{i=1}^N (work_i \times t_{optimized_i} \times r_{avail}) \quad (2)$$

Communication delay can be categorized into two types of delay that are communication delay from a cluster member to the cluster head (t_{in}) within the same cluster and also delay from the local cluster head to the remote cluster head (t_{out}). In predicting the communication time cost, we consider the bandwidth of the communication (BW). For t_{in} case, maximum $t_{in(i)}$ value will be used as the local communication cost considering the fact that each member could have a different t_{in} value. In t_{out} , the total work of cluster head ($work_{CH}$) will be divided by its bandwidth (BW_{CH}).

$$t_{in} = \max_{1 \leq i \leq N} \frac{work_i}{BW_i} \quad (3) \quad t_{out} = \frac{work_{CH}}{BW_{CH}} \quad (4)$$

Therefore, the estimated elapsed time of completing tasks locally (T_{local}) and doing offloading (T_{remote}) can be written as (5) and (6) respectively. (Given that the remote cluster has j members)

$$T_{local} = \left[\sum_{i=1}^N (work_i \times t_{optimized_i}) \times r_{avail} \right] + \max_{1 \leq i \leq N} \frac{work_i}{BW_i} \quad (5)$$

$$T_{remote} = \sum_{j=1}^N \left[(work_j \times t_{optimized_j}) \times r_{avail} \right] + \max_{1 \leq j \leq N} \frac{work_j}{BW_j} + \frac{work_{CH}}{BW_{CH}} \quad (6)$$

Based on the expected response time from (5) and (6), the offloading decision engine can decide whether to compute locally or offload to the remote cluster. By sharing the task opportunistically, the clusters' task could be distributed more evenly; therefore it would likely to give a higher operation time to each drone because the scheme will prevent usage

exploitation of one single cluster. Borrowing the available computing resources from other cluster would likely to decrease the response time of the drones.

IV. CONCLUSIONS

Drones are gaining their momentums proven by many services are provided by the drones nowadays. Because of more complex works as the technology grows, utilization of multiple UAVs or drone clusters is preferred given that clusters of drones are capable of increasing the coverage area, reducing the response time, and offering more reliability rather than a single UAV. But, still drones have limited battery and computing power; therefore in order to increase their operating time and to reduce the response time, in this paper we propose a scheme to do computational offloading opportunistically between drone clusters. By estimating the elapsed response time of processing tasks locally or remotely, the proposed method will adaptively offload some works to a remote drone cluster. By using the proposed scheme, we can increase the drone operation time by distributing the workload more evenly and also reduce the response time by borrowing available computing resources from the other drone clusters. For future work, we are going to make network simulator (ns3) based simulation for our proposed scheme and also implement it in a real test bed environment.

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