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An Offloading Decision Scheme for a Multi-Drone System

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***Abstract*:** *In the case of a single drone system, a drone should commit its task to the cloud to reduce task completion time and energy consumption. However, a multi-drone system, where several drones are connected to each other, can divide a task into small tasks and assign each small task to drones to improve responsibility. In this paper, we propose an offloading decision scheme that considers task completion time and energy consumption. The proposed scheme compares the cost of executing small tasks on the drones with the cost of committing a task to the cloud and decides offloading a task only if the cost of offloading is definitely smaller than the cost of using multiple drones. Our simulation results show that the proposed decision scheme is necessary because offloading spends more energy and time in some cases.*

Keywords: *Computation offloading, multi-drone systems, cloud computing, task completion time, energy consumption.*

1. Introduction

The application of drones and related technologies have rapidly grown in the past few years. Application developers and researchers are realizing the potential of drones in applications such as the smart city, remote sensing, surveillance systems, disaster management, and border security [1]. A drone cannot execute a heavy task because it has limited resources including processing capability, storage, bandwidth and energy. Cloud computing can provide an energy and time saving technique called computation offloading to a drone [2]. A drone can save its energy through renting resources from the cloud.

However, a multi-drone system is different from a single drone system as summarized in Table 1 [3]. In a single drone system, an expensive large drone is used for a task and covers a large area. The drone communicates with a ground control center directly. In a multi-drone system, drones are smaller and less expensive and work in a coordinated manner. The drones communicate among other drones and some of the drones communicate with a ground control center directly. The cooperation of multiple drones in a network also improve the performance and the coverage area [4]. These connected drones integrate with cloud computing and are accessed as a cloud resource called a cloudlet [5]. In this system, drones register and provide their resources including computing power, storage, sensors, cameras, and actuators to achieve mission goals.

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TABLE I: Single And Multi-Drone System Comparison

Feature	Single Drone System	Multi-drone System
Reliability	Low	High
Scalability	Low	High
Coverage	Low	High
Task overhead	High	Low
Accuracy	Low	High
Cost	High	Low
Complexity	Low	High
Coordination	Low	High

In a single drone system, a drone should commit a heavy task to the cloud to reduce task completion time and energy consumption because a drone has resource constraints that prevent the drone from performing many things concurrently. However, in a multi-drone system, a heavy task is able to divide into small tasks and these small tasks are assigned to each drone with short distance communication among the drones. Executing a task with connected drones, which collects and processes data from themselves, is also more efficient than offloading the task. While drones send their data to the ground center, they use much energy and interference increases communication delay. Therefore, we propose an offloading decision scheme that compares the cost of executing small tasks on the drones with the cost of offloading a task. The proposed scheme, which considers both the task completion time and the energy consumption, shows better performance than the fully offloading scheme in multi-drone systems.

2. Proposed Offloading Decision Scheme

2.1. System Overview

Face recognition by the crowd surveillance system is a typical application using drones and the computation offloading because the offloading of video data processing to the cloud is necessary to reduce the computational overhead of drones. If a drone monitors numerous people in a huge space, it is impossible to execute video data processing on the drone. Experimental results of Motlagh et al. [6] show that offloading reduces energy consumption and processing time more than 100 times in comparison to performing local processing of a drone.

We assume the crowd surveillance system using multiple drones as shown Fig. 1. A user sends images of who the user is wanting to find to the cloud. The cloud sends location information to the ground control center and the ground control center forces the drones to move to the target area. When the drones arrive to the target area, the drones divide the target area into small areas and monitor their assigned area. In the case of offloading, the drones send their video data to the cloud periodically through the ground control center. The cloud sends a result to the user after conducting video data processing and analyzing.

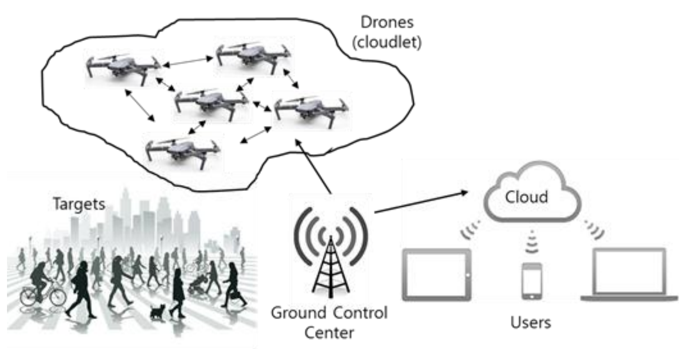

Fig. 1 Crowd surveillance system with multiple drones

In the case of using drones as a cloudlet, the drones request face images that are submitted by a user to the cloud. Each drone sends a result to the cloud after conducting video data processing and analyzing with received face images. In a multi-drone system, executing a small task on each drone is more efficient than the computation offloading, which depends on the conditions because a wireless communication module spends more energy than a data processing unit.

Luo et al. [7] proposed system architecture that divides data processing into two parts. One is computing within each cloudlet that is composed of multiple drones and the other is computing within the cloud. They also analyzed the availability and stability of the proposed system. In terms of coordinating and managing the network among drones, Sharma et al. [8] inspected characteristics of flying ad hoc networks and summarized data sending and receiving algorithms. Therefore, we only focus on designing the offloading decision scheme based on existing studies.

2.2. Cost Analysis Model

We designed a cost analysis model for deciding whether to offload a task or to execute a small task on the drones. Table 2 shows a notation list of equations in this paper.

TABLE II: Notations

Items	Descriptions
W_t	Weight of task completion time part
W_e	Weight of energy consumption part
T_d	Task completion time of executing small tasks on the drones
T_o	Task completion time of offloading
E_d	Energy consumption of executing small tasks on the drones
E_o	Energy consumption of offloading
N	Number of drones
L_i	Length of Instructions
f	Processing capability of a drone
t_{tx}, t_{rx}	Data transmission delay per byte (sending, receiving)
D_{arg}	Data size of face images
D_{ret}	Data size of result
D^i_{video}	Data size of video streaming of *ith* drone
e_f	Energy consumption of executing an instruction
e_{tx}, e_{rx}	Energy consumption of data transmission per byte (sending, receiving)

Equation (1) shows our cost analysis function that considers task completion time and energy consumption. If the analysis result (C) is less than 1, offloading a task is more efficient than executing small tasks on the drones. This means that offloading is conducted when the offloading guarantees the efficiency in terms of task completion time and energy consumption.

$$C = W_t \times \frac{T_o}{T_d} + W_e \times \frac{E_o}{E_d}, if\ C \leq 1\ then\ offlading \quad (1)$$

We assume homogeneous multiple drones to simplify our model. This means that all drones have the same capacity and energy level. Under this assumption, we define the task completion time of executing small tasks on the drones as shown (2). A task with length L_i is divided into N small tasks. The completion time of small tasks is determined by each drone's processing power (f). Each drone needs face images to conduct the fact recognition process and sends the analysis result to the cloud. This communication delay is determined by a maximum value among the drone's delay. We just add one delay because all drones have the same capacity.

$$T_d = \frac{L_i}{N \cdot f} + t_{rx} \cdot D_{arg} + t_{tx} \cdot D_{ret} \quad (2)$$

We define the task completion time of offloading a task as shown (3). We ignore the processing time of the cloud because the cloud provides powerful computing resources and this kind of image processing is finished within a few seconds. Therefore, the task completion time of offloading only depends on maximum transmission delay during sending data from a drone to the cloud.

$$T_o = max(t_{tx}^i \cdot D_{video}^i), if \ 1 \leq i \leq N \tag{3}$$

We define the energy consumption of executing small tasks on the drones as shown (4). All drones spend same energy to execute their small tasks. Thus the energy consumption of a task is determined by instruction length and the energy consumption per an instruction of a drone. We also consider the energy consumption while all drones receive face images from the cloud and send results to the cloud. If a drone receives face images form the cloud and shares the received data among other drones, it can save more energy. However, we remain this issue for further research.

$$E_d = L_i \cdot e_f + N(e_{rx} \cdot D_{arg} + e_{tx} \cdot D_{ret}) \tag{4}$$

We define the energy consumption of offloading a task as shown (5). In the case of energy consumption, we also ignore the energy consumption of the cloud because we only focus on the drone's view. The energy consumption of offloading is determined by the data size of video streaming of each drone.

$$E_o = \sum_{i=0}^{N} (e_{tx}^i \cdot D_{video}^i) \tag{5}$$

3. Experimental Results

We conducted a simulation to verify our cost analysis model and offloading decision scheme. Table 3 shows a list of parameter values that are used for our simulation and parameters related to wireless communication is referred from the analysis results of Huang et al. [9].

TABLE III: Parameter Values

Items	Values
W_t, W_c	0.5
N	[10, 100]
L_i	[100000, 500000] MI
f	1.2 GHz, 2441 MIPS
t_{tx}	4 Mbytes
t_{rx}	4 bytes
D_{arg}	40 Mbytes
D_{ret}	0.6278 µs
D_{video}^i	1.4184 µs
e_f	2.574 µW/MIPS
e_{tx}	0.051 µW/bps
e_{rx}	0.438 µW/bps

Fig. 2 shows a comparison of task completion time between offloading a task and executing small tasks on drones with the number of drones. In the case of offloading (*T_offloading*), the task completion time does not change because offloading does not depend on the number of drones. However, in the case of executing small tasks on the drones (*T_drones*), the task completion time decreases rapidly because the length of instruction decreases by increasing the number of drones.

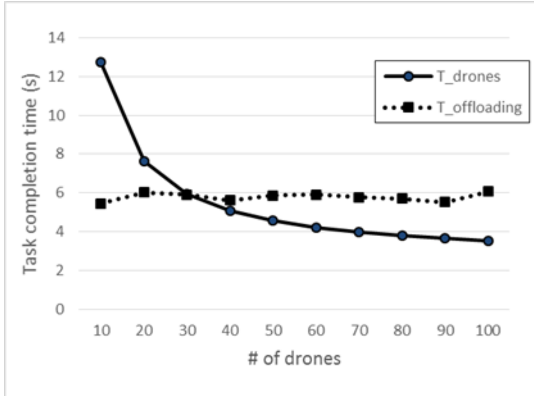

Fig. 2: Comparison of task completion time comparison to the number of drones

Fig. 3 shows a comparison of task completion time comparison between offloading a task and executing small tasks on the drones with the length of instructions. In the case of offloading (*T_offloading*), the task completion time also does not change because offloading does not depend on the length of instruction. However, in the case of executing small tasks on the drones (T_drones), the task completion time increases because the processing overhead of each drone increases by increasing the length of instruction.

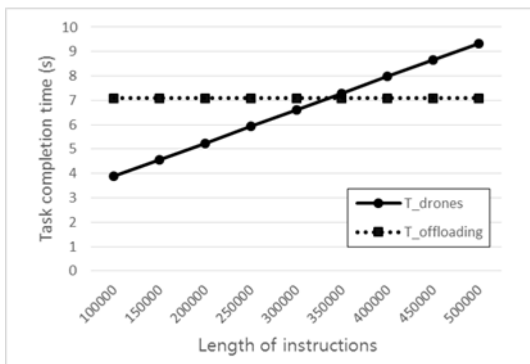

Fig. 3: Comparison of task completion time to the length of instructions

Fig. 4 shows a comparison of energy consumption comparison between offloading a task and executing small tasks on the drones with the number of drones. In the case of the offloading (*T_offloading*), the energy consumption increases rapidly because each node spends energy to send its video data to the cloud. However, in the case of executing small tasks on the drones (*T_drones*), the energy consumption slightly increases because the size of transmission data between a drone and the cloud is much smaller than the one of offloading.

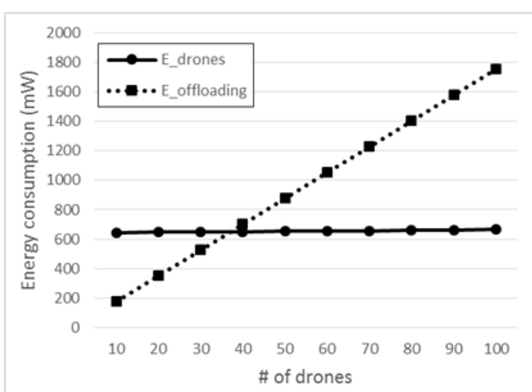

Fig. 4: Comparison of energy consumption to the number of drones

Fig. 5 shows a comparison of energy consumption comparison between offloading a task and executing small tasks on drones with the number of drones. In the case of offloading (*T_offloading*), the energy consumption does not change because the energy consumption does not depend on the length of instructions. However, in the case of executing small task on the drones (*T_drones*), the energy consumption linearly increases because the drones spend more energy to process the increasing instructions.

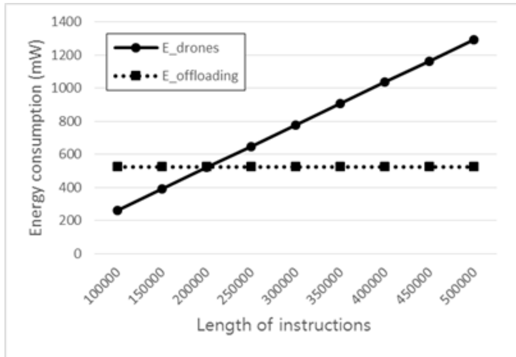

Fig. 5: Comparison of energy consumption to the length of instructions

4. Conclusions

Drones are used not only for military applications but also for public or commercial applications. With developing drone related technologies, several types and numbers of drone are using an application. Drones can compose a network and share their resources among other drones. Drones with limited resources cannot conduct every task, even though drones are more powerful than before. However, drones also cannot commit all tasks to the cloud. We proposed an offloading decision scheme that considers responsibility and energy for a multi-drone system. Simulation results also show that selective offloading is more efficient than fully offloading or executing small tasks on the drones by changing application features.

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