Mobile Edge Computing System Via Unmanned Aerial Vehicles: An Energy Efficient Task Offloading Framework

Madyan Alsenwi, Yan Kyaw Tun, Shashi Raj Pandey, and Choong Seon Hong

Department of Computer Science and Engineering, Kyung Hee University, South Korea

{malsenwi, ykyawtun7, shashiraj, cshong}@khu.ac.kr

Abstract

Due to the exponential growth of the internet of things devices (IoTDs), more and more data-oriented applications are coming up. However, it is challenging to process collected data locally at the IoTDs due to its limited computation capacity and power. In this work, we propose a Unmanned Aerial Vehicles based mobile edge computing system. Specifically, we formulate an optimization problem that optimizes the task offloading subject to the latency constraint of all IoTDs and the limitation of computation capacity resources while minimizing the energy consumption of IoTDs. Simulation results show the efficiency of the proposed approach.

Keywords -Unmanned Aerial Vehicles (UAVs), mobile edge computing, task offloading.

1. Introduction

Due to the exponential growth of the internet of things devices (IoTDs), more computation oriented applications are coming up in our life which are limited capacity and power devices and hence, it is difficult to process their data locally. Deploying a mobile edge computing (MEC) server at the network edge which allows the IoTDs to offload their data for processing at the MEC server is a promising approach to overcome the limitations of IoTDs [1, 2]. However, in some cases IoTDs will be far from the MEC services and out of the coverage of the mobile infrastructure, e.g. smart farming in rural areas, and military operation. In such cases, it is difficult for IoTDs to use the MEC services.

Recently, Unmanned aerial vehicles (UAVs) have been widely deployed due to its low cost of deployment. Therefore, we can save the deployment cost of the mobile infrastructures and provide remote MEC services to the IoTDs on demand by deploying an MEC-enabled UAV. To this end, we propose an energy-efficient UAV-assisted edge computing system in this work. Recently, research works focusing on UAV are gaining attention in both academia and industry. For example, authors in [3] proposed a UAV-based MEC system, where a UAV can power the IoTDs by leveraging the wireless power transfer technology. They modeled the system as an optimization problem that optimizes the computing resource allocation, IoTDs association, wireless power duration, UAV hovering time, and the service sequence of the IoTDs while minimizing the energy consumption of the UAV. The work in [4] proposed a UAV-MEC system considering the physical layer security. A non-convex optimization problem for secure UAV-MEC system was formulated, with the objective is to minimize the system energy, and then transformed to convex problems.

In this work, we introduce an energy-efficient UAV-assisted MEC system. Specifically, we optimize the task offloading to the UAV in order to minimize the computation power of IoTDs.

The remaining parts of this paper are organized as follows: Section II presents the system model and problem formulation. Specifically, the local computing model and the problem formulation are discussed in this section. The performance evaluation of the proposed algorithm is introduced in section III. Finally, section IV concludes the paper and presents some directions for future work.

2. System Model and Problem Formulation

We consider a UAV-assisted MEC system, as shown in Fig. 1, which includes a single UAV working as an aerial base station attached with an edge server and a set of IoT mobile devices $\mathcal{S} = \{1, 2, \ldots, S\}$. The UAV is hovering above the ground mobile devices and provides computation services. At the UAV hovering period, the UAV can communicate and provide computation services to the ground devices. We divide the UAV's hovering period into equally-length time slots $\mathcal{N} = \{1, 2, \ldots, N\}$. The horizontal coordinate of each ground device is assumed to be fixed $c_s = [x_s, y_s]^T, \forall s \in \mathcal{S}$ while the UAV is hovering at a fixed altitude H with horizontal coordinates $u(n) = [x(n), y(n), H]^T, \quad \forall n \in \mathcal{N}$. Therefore, we can calculate the distance between the UAV and a device s at time slot n as follows

$$d_s(n) = \sqrt{H^2 + ||\boldsymbol{u}(n) - \boldsymbol{c}_s||^2}, \ \ \forall s \in \mathcal{S}, \forall n \in \mathcal{N}. \quad (1)$$

In [5–7] authors have shown that the communication channel (air-to-ground) can be modeled by the Line-of-Sight (LoS) link even if the UAV is at a moderate altitude. Moreover, the Doppler effect, which comes from the UAV mobility, is considered to be calculated at the receiver. Therefore,

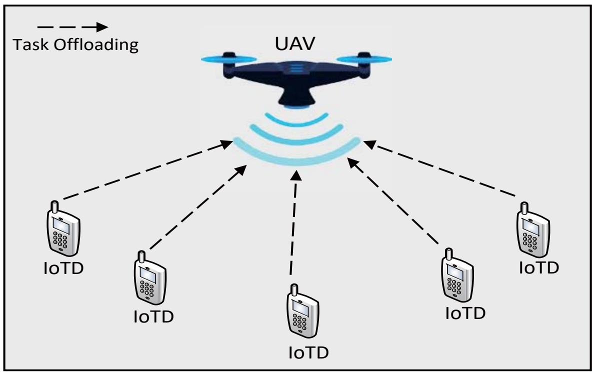

Figure 1: Illustration of the proposed system model.

the LoS channel gain is given by [8, 9]

$$g_s(n) = g_0 d_s^{-2}(n) = \frac{g_0}{H^2 + ||u(n) - c_s||^2}, \forall s \in \mathcal{S}, \forall n \in \mathcal{N}, \quad (2)$$

where g_0 is the channel gain at the reference distance d_0.

At each time slot n, each mobile device has a computation task, and it can be expressed as a tuple $\{\mu_s, I_s(n), T_s(n)\}$ where μ_s is the required computation capacity to execute one bit of input data, $I_s(n)$ and $T_s(n)$ are the total input data size and the computation deadline of the task. The mobile device offloads a portion of the computation task to the UAV because the edge server at the UAV has more powerful computation capability and executes the rest locally. Let us denote the portion of the task offloaded to the UAV as $l_s(n)$. Therefore, the fraction of the task executed locally on the mobile device is $(I_s(n) - l_s(n))$. Then, the local computation execution latency/delay of the device s at time slot n is as follows

$$t_s^l(n) = \frac{\mu_s(I_s(n) - l_s(n))}{\nu_s(n)}, \quad \forall s \in \mathcal{S}, \forall n \in \mathcal{N}, \quad (3)$$

where $\nu_s(n)$ is the local computation resources of the user s required to execute $(I_s - l_s)$ within t_s^l. Therefore, the local computation time t_s^l data depends mainly on the variables l_s and ν_s. Furthermore, the local energy consumption of the device s at time slot n is given by [10, 11]

$$E_s(n) = k^l \nu_s^2(n) \mu_s(I_s(n) - l_s(n)), \quad \forall s \in \mathcal{S}, \forall n \in \mathcal{N}, \quad (4)$$

where k^l is a constant which depends on the chip architecture of the IoTD.

2.1 Problem Formulation

In this work, we consider an energy-minimization problem in UAV-aided mobile edge computing system with the aim is to minimize the energy consumption of IoTDs by optimizing the task offloading ($\boldsymbol{l}$), where $\boldsymbol{l} = \{l_s(n), \forall n \in \mathcal{N}, \forall s \in \mathcal{S}\}$.

Therefore, we can formulate the optimization problem as follows

$$\min_{\boldsymbol{l}} \sum_{n=1}^{N} \sum_{s=1}^{S} E_s(n) \quad (5)$$

$$\text{s.t. } t_s^l(n) \leq T_s(n), \forall s \in \mathcal{S}, \forall n \in \mathcal{N}, \quad (6)$$

$$l_s(n) \leq I_s(n), \forall s \in \mathcal{S}, \forall n \in \mathcal{N}. \quad (7)$$

The Lagrangian function of the optimization problem (5) is given as

$$\mathcal{L}(\boldsymbol{l}, \boldsymbol{\lambda}, \boldsymbol{\delta}, \boldsymbol{\theta}) = \sum_{n=1}^{N} \sum_{s=1}^{S} E_s^l(n) + E_s^{up}(n) + \sum_{n=1}^{N} \sum_{s=1}^{S} \lambda_s(n)\Big(t_s^l(n) - T_s(n)\Big) + \sum_{n=1}^{N} \sum_{s=1}^{S} \theta_s(n)\Big(l_s(n) - I_s(n)\Big). \quad (8)$$

We calculate the second derivative of (8) as follows

$$\frac{\partial \mathcal{L}}{\partial l_s(n)} = -k^l \nu_s^2(n)\mu_s(n) + \frac{p_s(n)}{R_s(n)} - \frac{\mu_s(n)}{\nu_s(n)} + \theta_s(n) + \lambda_s(n)\Big(\frac{1}{R_s(n)} + \frac{\mu_s(n)}{\gamma_s(n)}\Big) \Rightarrow \frac{\partial^2 \mathcal{L}}{\partial l_s^2(n)} = 0. \quad (9)$$

Hence, the problem (5) is a convex optimization problem as $\frac{\partial^2 \mathcal{L}}{\partial l^2} \geq 0$. Therefore, we can use ECOS solver in the CVXPY to solve it.

3. Simulations

To evaluate the performance of the proposed algorithm, we consider a multiuser MEC system with a single UAV, where the MEC server having a maximum computation capacity of 1GHz is deployed at the UAV. The users are randomly scattered within the UAV's coverage area and every user has computation tasks to be executed. The input data size of tasks and the required CPU cycles to execute one bit of input data are randomly generated between [0.1, 0.4]MB and [10, 25]cycles. The maximum tolerable latency to execute a computation task of each user is between [30, 100]s.

In Fig. 2, the optimal value of $\mathcal{Q} = \sum_{n=1}^{N} \sum_{s=1}^{S} E_s(n)$ is calculated for different number of users. Moreover, we compare the performance of the proposed algorithm with the equal resources sharing scheme. Under equal resources sharing scheme, the UAV allocates its physical resource to all users equally. From Fig. 2, we observe that the proposed scheme outperforms the equal resources sharing schemes.

4. Conclusion

In this work, we have proposed a UAV-aided mobile edge computing system. Specifically, we have formulated an

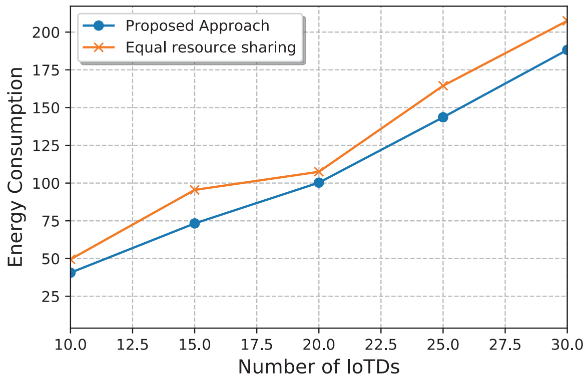

Figure 2: Energy Consumption under different number of users at $\beta = 1$.

energy-efficient resource allocation problem that aims to minimize the energy consumption of IoTDs by optimizing task offloading. Simulation results have shown the efficiency of the proposed algorithm. In the future, we will consider multiple UAVs scenario and take into account the power consumption of both UAVs and IoTDs.

Acknowledgement

This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIT) (No.2015-0-00557, Resilient/Fault-Tolerant Autonomic Networking Based on Physicality, Relationship and Service Semantic of IoT Devices) and by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea goverment(MSIT) (No.2019-0-01287, Evolvable Deep Learning Model Generation Platform for Edge Computing). *Dr. CS Hong is the corresponding author.

References

[1] P. Mach and Z. Becvar, "Mobile edge computing: A survey on architecture and computation offloading," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 3, pp. 1628–1656, 2017.

[2] M. Alsenwi, Y. K. Tun, S. R. Pandey, N. N. Ei, and C. S. Hong, "Uav-assisted multi-access edge computing system: An energy-efficient resource management framework," in *the 34rd International Conference on Information Networking (ICOIN), Barcelona, Spain (Accepted)*, January, 2020.

[3] Y. Du, K. Yang, K. Wang, G. Zhang, Y. Zhao, and D. Chen, "Joint resources and workflow scheduling in uav-enabled wirelessly-powered mec for iot systems," *IEEE Transactions on Vehicular Technology*, 2019.

[4] T. Bai, J. Wang, Y. Ren, and L. Hanzo, "Energy-efficient computation offloading for secure UAV-edge-computing systems," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 6, pp. 6074–6087, jun 2019.

[5] X. Lin, V. Yajnanarayana, S. D. Muruganathan, S. Gao, H. Asplund, H.-L. Maattanen, M. Bergstrom, S. Euler, and Y.-P. E. Wang, "The sky is not the limit: Lte for unmanned aerial vehicles," *IEEE Communications Magazine*, vol. 56, no. 4, pp. 204–210, 2018.

[6] M. Alsenwi, N. H. Tran, M. Bennis, A. K. Bairagi, and C. S. Hong, "eMBB-URLLC resource slicing: A risk-sensitive approach," *IEEE Communications Letters*, vol. 23, no. 4, pp. 740–743, apr 2019.

[7] M. Alsenwi, I. Yaqoob, S. R. Pandey, Y. K. Tun, A. K. Bairagi, L. won Kim, and C. S. Hong, "Towards coexistence of cellular and WiFi networks in unlicensed spectrum: A neural networks based approach," *IEEE Access*, vol. 7, pp. 110 023–110 034, 2019.

[8] M. Alsenwi, S. R. Pandey, Y. K. Tun, K. T. Kim, and C. S. Hong, "A chance constrained based formulation for dynamic multiplexing of eMBB-URLLC traffics in 5g new radio," in *2019 International Conference on Information Networking (ICOIN)*. IEEE, jan 2019.

[9] M. Alsenwi and C. S. Hong, "Resource scheduling of urllc/embb traffics in 5g new radio: A punctured scheduling approach," in *Korean Computer Congress (KCC 2018)*, 2018.

[10] S. R. Pandey, M. Alsenwi, Y. K. Tun, and C. S. Hong, "A downlink resource scheduling strategy for URLLC traffic," in *2019 IEEE International Conference on Big Data and Smart Computing (BigComp)*. IEEE, feb 2019.

[11] M. Alsenwi, H. Elsayed, and M. Elghoneimy, "Optimization of channel selection in cognitive heterogeneous wireless networks," in *2015 11th International Computer Engineering Conference (ICENCO)*. IEEE, dec 2015.