Multi-dimensional knapsack problem for Resource Allocation to UEs through UAV

Conference Paper · December 2021

3 authors:

Umer Majeed
Kyung Hee University
24 PUBLICATIONS **153** CITATIONS

Sheikh Salman Hassan
Kyung Hee University
17 PUBLICATIONS **25** CITATIONS

Choong Seon Hong
Kyung Hee University
961 PUBLICATIONS **11,244** CITATIONS

Multi-dimensional knapsack problem for Resource Allocation to UEs through UAV

Umer Majeed, Sheikh Salman Hassan, Choong Seon Hong
Department of Computer Science and Engineering,
Kyung Hee University, Yongin, South Korea
Email: {umermajeed, salman0335, cshong}@khu.ac.kr

Abstract

Unmanned aerial vehicles (UAVs) are an indispensable component of future wireless networks. UAV can not only provide edge-computing services but also act as a router to the backhaul for the user devices. In this paper, we considered the problem of allocating communication and computing resources to UEs via UAV as a multi-dimensional knapsack problem. We used OR-Tools to solve the multi-dimensional knapsack problem in order to maximize the utility of the UAV. OR-Tools solves the NP-hard multi-dimensional knapsack problem with brand-and-bound algorithms.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) will be an indispensable component in future wireless networks [1], [2], [3], [4], [5]. The application of UAVs in smart cities [6] includes federated learning [7], [8], [9], [10], [11], surveillance [12], intelligent transportation management system and terrestrial communication. Unmanned aerial vehicles can also be an integral part of Space-Oceanic Networks [13], [14]. UAVs can not only provide communication services to the UEs to the backhaul but also provide computing services by acting as an edge server.

The contribution of this study is summarized as follows:

- We formulated the multi-dimensional knapsack problem for the communication and computing resource allocation to UEs through UAV.
- We solved the multi-dimensional knapsack problem using OR-Tools which uses the brand-and-bound algorithm to maximize the utility of UAV.

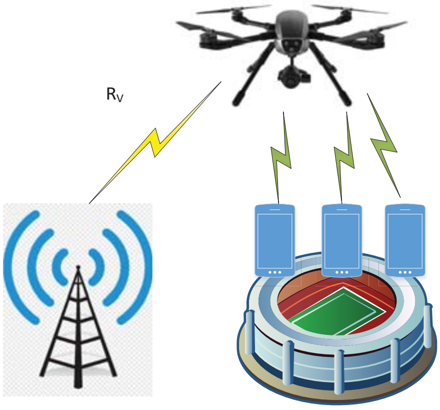

Fig. 1. System model

The rest of the paper is organized as follows: Section II illustrates the system model for resource allocation to UEs through UAV. Section III formulates the multi-dimensional knapsack problem for resource allocation. Section IV gives the simulation results, and Section V concludes our work.

II. SYSTEM MODEL

A UAV V is operating on frequency f_v and has the backhaul rate of $\mathcal{R}_V$ as shown in Fig. 1. There is a set $\mathcal{N}$ of N UEs to be processed by the UAV. The UAV has Computing

---

This work was supported by the IITP Grant Funded by the Korea Government (MSIT) (No. 2020-0-00364, Development of Neural Processing Unit and Application Systems for Enhancing AI-Based Automobile Communication Technology) and in part by the MSIT(Ministry of Science and ICT), Korea, under the Grand Information Technology Research Center support program(IITP-2021-0-00742) supervised by the IITP(Institute for Information & communications Technology Planning & Evaluation) *Dr. CS Hong is the corresponding author.

Energy E available such that it can operate for time $\mathcal{T}_V$ at frequency f_v. Each UE_i has task T_i and willing to pay price u_n to the UAV V. That is UE_i has utility u_n to the UAV, if it is selected. Task T_i takes time t_i to be processed by the UAV. The UE_i also needs the constant bandwidth r_i from the UAV. The contract between the UAV and UEs is that it needs to both compute the computing task and also provide the BW from the backhaul link to the selected UEs.

III. PROBLEM FORMULATION

Let x_i be the binary variable indicating that the UE_i is selected by UAV to allocate its resources. then the total utility of UAV to be maximized is

$$\mathbf{P1:}\ \underset{\mathbf{x}}{\operatorname{argmax}}\, U_V = \mathbf{x}_i * u_i \tag{1}$$

s.t.

$$\sum_i x_i * t_i \leq \mathcal{T}_V \tag{C1}$$

$$\sum_i x_i * r_i \leq \mathcal{R}_V \tag{C2}$$

$$x_i \in \{0, 1\} \tag{C3}$$

Constraint C1 indicates that the total allotted computing time can not exceed $\mathcal{T}_V$. Constraint C2 indicates that the total allotted data rate can not exceed $\mathcal{R}_V$. Constraint C3 indicate that x_i is binary variable with $x_i = 1$ if the resources are allocated to UE_i and $x_i = 0$ if the resources are not allocated to UE_i. Problem **P1** is Multidimensional Knapsack Problem (MKP) [15], [16] which is attained by adding additional weight constraints to the one-dimensional basic knapsack problem (KP) [17]. This problem falls under Integer Linear Programming (ILP) and is an NP-hard problem [18].

IV. SIMULATION RESULTS

The multidimensional knapsack problem defined in **P1** is solved using OR-Tools [19]. OR-Tools employs branch-and-bound algorithms [20], [21] to solve the multidimensional knapsack problem. We set $\mathcal{T}_V = 20$ and $\mathcal{R}_V = 20$. The r_i, t_i, and u_i for 15 UEs are as indicated in Fig. 2.

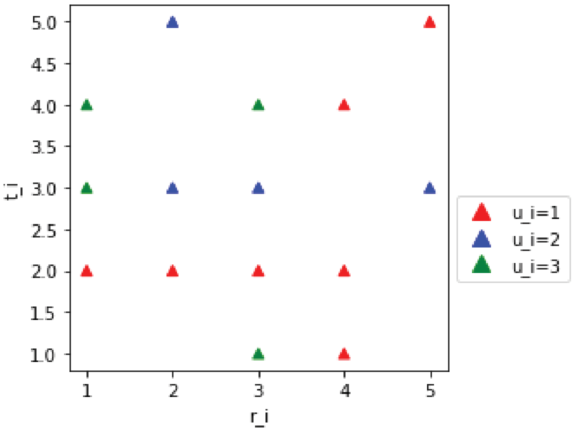

Fig. 2. r_i, t_i, and u_i for 15 UEs

We used OR-Tools to solve the multidimensional knapsack problem defined in **P1**. The selected items to maximize the utility of UAV are indicated in Fig. 3. The total utility for UAV is $U_V = 17$.

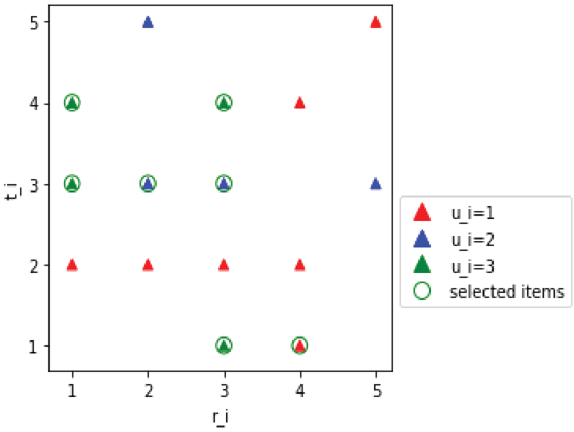

Fig. 3. Selected UEs to maximize utility of UAV by OR-Tools

V. CONCLUSION

In this study, We formulated the issue of communication and computing resource allocation to UEs through UAV as a multi-dimensional knapsack problem. To maximize the utility of the UAV, we solved the multi-dimensional knapsack problem using OR-Tools. OR-Tools uses the brand-and-bound algorithms underneath to solve the NP-hard multi-dimensional knapsack problem.

REFERENCES

[1] S. S. Hassan, Y. M. Park, and C. S. Hong, "On-demand mec empowered uav deployment for 6G time-sensitive maritime internet of things," in

2021 22nd Asia-Pacific Network Operations and Management Symposium (APNOMS), 2021, pp. 386–389.

[2] S. S. Hassan, S. W. Kang, and C. S. Hong, “Unmanned Aerial Vehicle Waypoint Guidance with Energy Efficient Path Planning in Smart Factory,” in *2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, September 2019, pp. 1–4.

[3] S. S. Hassan and C. S. Hong, “Reliable localization in maritime search and rescue operation by utilizing unmanned aerial vehicle,” *Korean Computer Congress (KCC)*, pp. 1064–1066, 2020.

[4] S. S. Hassan, U. Majeed, and C. S. Hong, “On-Demand Unmanned Aerial Vehicle Deployment and Profit Maximization for Internet of Maritime Things Networks,” *Korean Computer Congress (KCC)*, pp. 156–158, 2021.

[5] A. Manzoor, K. Kim, S. R. Pandey, S. M. A. Kazmi, N. H. Tran, W. Saad, and C. S. Hong, “Ruin Theory for Energy-Efficient Resource Allocation in UAV-Assisted Cellular Networks,” *IEEE Transactions on Communications*, vol. 69, no. 6, pp. 3943–3956, 2021.

[6] U. Majeed, L. U. Khan, I. Yaqoob, S. A. Kazmi, K. Salah, and C. S. Hong, “Blockchain for IoT-based smart cities: Recent advances, requirements, and future challenges,” *Journal of Network and Computer Applications*, vol. 181, p. 103007, 2021.

[7] U. Majeed and C. S. Hong, “FLchain: Federated Learning via MEC-enabled Blockchain Network,” in *2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS)*, 2019, pp. 1–4.

[8] U. Majeed, L. U. Khan, and C. S. Hong, “Cross-silo horizontal federated learning for flow-based time-related-features oriented traffic classification,” in *2020 21st Asia-Pacific Network Operations and Management Symposium (APNOMS)*, 2020, pp. 389–392.

[9] L. U. Khan, U. Majeed, and C. S. Hong, “Federated Learning for Cellular Networks: Joint User Association and Resource Allocation,” in *2020 21st Asia-Pacific Network Operations and Management Symposium (APNOMS)*, 2020, pp. 405–408.

[10] U. Majeed, S. S. Hassan, and C. S. Hong, “Cross-silo model-based secure federated transfer learning for flow-based traffic classification,” in *2021 International Conference on Information Networking (ICOIN)*, 2021, pp. 588–593.

[11] U. Majeed and C. S. Hong, “Blockchain-assisted Ensemble Federated Learning for Automatic Modulation Classification in Wireless Networks,” *Proc. of the KIISE Korea Computer Congress (KCC)*, pp. 756–758, 2019.

[12] Y. Jin, Z. Qian, and W. Yang, “UAV Cluster-Based Video Surveillance System Optimization in Heterogeneous Communication of Smart Cities,” *IEEE Access*, vol. 8, pp. 55 654–55 664, 2020.

[13] S. S. Hassan, U. Majeed, and C. S. Hong, “Reliable Integrated Space-Oceanic Network Profit Maximization by Bender Decomposition Approach,” in *proceedings of International Conference on Information Networking (ICOIN)*, Jeju Island, S. Korea, January 2021, pp. 565–570.

[14] S. S. Hassan and C. S. Hong, “Free Space Optical Wireless Communication Link Analysis for LEO Satellites based Future Generation Maritime Networks,” *Korea Software Conference (KSC)*, pp. 878–880, 2020.

[15] J. Tavares, F. B. Pereira, and E. Costa, “Multidimensional Knapsack Problem: A Fitness Landscape Analysis,” *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, vol. 38, no. 3, pp. 604–616, 2008.

[16] Z. Li, L. Tang, and J. Liu, “A memetic algorithm based on probability learning for solving the multidimensional knapsack problem,” *IEEE Transactions on Cybernetics*, pp. 1–16, 2020.

[17] X. Liang, A. K. Qin, K. Tang, and K. C. Tan, “QoS-Aware Web Service Selection with Internal Complementarity,” *IEEE Transactions on Services Computing*, vol. 12, no. 2, pp. 276–289, 2019.

[18] M. Chih, “Self-adaptive check and repair operator-based particle swarm optimization for the multidimensional knapsack problem,” *Applied Soft Computing*, vol. 26, pp. 378–389, 2015.

[19] “OR Tools - The Knapsack Problem.” [Online]. Available: https://developers.google.com/optimization/bin/knapsack

[20] J. C. Zavala-Díaz, M. A. Cruz-Chavez, M. H. Cruz-Rosales, and J. Frausto-Solís, “Branch and bound hybrid algorithm to determine the exact or approximate solution of the 0/1 knapsack problem with one parameter,” in *2008 Electronics, Robotics and Automotive Mechanics Conference (CERMA ’08)*, 2008, pp. 252–258.

[21] A. E. Ezugwu, V. Pillay, D. Hirasen, K. Sivanarain, and M. Govender, “A Comparative Study of Meta-Heuristic Optimization Algorithms for 0 – 1 Knapsack Problem: Some Initial Results,” *IEEE Access*, vol. 7, pp. 43 979–44 001, 2019.