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Flying Fog Mobile Edge Computing Based on UAV-Assisted for IoT Nodes in Smart Agriculture

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Abstract: *Flying Fog Mobile Edge Computing can play a pivotal part in the field of smart agriculture. Moreover, is an ideal choice for the significant features it enjoys such as its capability of functioning in remote locations, its wide coverage of areas, sufficient bandwidth, as well as its ability of dealing with connectivity issues. Hence, it is essential for smart agriculture provided with IoT devices to utilize offloading data in a real time and execution the satisfactory steps for a certain circumstance by using flying fog mobile edge computing. Flying Fog Mobile Edge Computing is a good choice to treat connectivity issues. In this paper, proposed a cooperation paradigm of UAVs and IoT devices towards smart agriculture for offloading and executing the computation tasks on-behalf IoT nodes by using dynamic programming algorithm and get satisfactory solution for constrained optimization problem and achieving minimize delay to accomplish tasks.*

Keywords: *UAVs, IoT, Mobile Edge Computing, IoT nodes.*

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Летающие мобильные граничные вычисления на базе БПЛА для узлов Интернета вещей в «умном» сельском хозяйстве

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Аннотация: *Летающие мобильные граничные вычисления могут сыграть ключевую роль в области «умного» (интеллектуального) сельского хозяйства. Кроме того, это идеальный выбор благодаря таким важным характеристикам, как возможность работы в удаленных местах, широкий охват территорий, достаточная пропускная способность, а также способность решать проблемы с подключением. Для «умного» сельского хозяйства, оснащенного IoT-устройствами, важно использовать выгрузку данных в режиме реального времени и выполнять удовлетворительные шаги для определенных обстоятельств с помощью мобильных граничных вычислений. Летающие мобильные граничные вычисления – хороший выбор для решения проблем с подключением. В статье предлагается парадигма сотрудничества БПЛА и «мир» IoT в интересах интеллектуального сельского хозяйства путем выгрузки и выполнения вычислительных задач от имени IoT-узлов за счет использования алгоритма динамического программирования и получения удовлетворительного решения задачи оптимизации с ограничениями, а также минимизации задержки для выполнения задач.*

Ключевые слова: *БПЛА, Интернет вещей, мобильные граничные вычисления, IoT-узлы.*

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1. Introduction

Unmanned Aerial Vehicles have been an important part to assist terrestrial networks. Thus, they can contribute considerably in providing extra functional diversity in assisting 5G and next generations of mobile networks. Moreover, for their ease of deployment and observability, it could be used in a different commercial applications and civil purposes such as surveying and mapping, aerial base stations, search and rescue, and development of new user equipment, deployed both for computing, data gathering, surveillance, provide connectivity, traffic management, etc. Moreover, the performance criteria of 5G networks in the context of enhanced reliability, low latency, peak throughput per connection, high speed, and consuming low power makes the UAVs one of the most important options to achieving all issues mentioned above.

A wide range of use cases can be imagined for UAVs which, in general, can be categorized into two important paradigms: the UAV acting as part of wireless communication infrastructure, and the UAV acting as a mobile terminal. Furthermore, terrestrial base stations BSs have been recently assisted by UAVs, hence, their capacity has been extended in terms of resource allocation and coverage. Also, they assist WSN (wireless sensor networks), IoT (Internet of things), and support Smart cities [1]. Forming flexible aerial platforms, UAVs can be easily employed in the sky [2]. In addition, using 5G networks, seamless connectivity can be well supported and multiple QoS requirements can be guaranteed for many devices, with a large amount of data being handled, which are generated by physical environments [3]. Thus, wireless communication systems of 5G and beyond can boost the support of platforms of aerial communication access. With such capacities, UAVs are considered an integral part of the future generation of mobile networks. They can work jointly as a single system [4]. UAVs have also been used for other purposes in smart agriculture provided by IoT devices like computing, aerial sensing, monitoring, data collection, tracking, and communication.

The current paper proposes a new computing paradigm which is flying fog edge computing based on UAV-MEC assisted IoT devices in smart agriculture. Where, IoT are small limited resources devices that generate data from the surrounding environment. The IoT devices don't have ability to do computing and processing the data because of they have limited resources [5]. In conventional techniques, the computing is implemented by transfer data to a central base station with server provided via multi-hops and relays, leading to delays and errors [6]. For such issues, flying fog computing based on UAV-MEC play a vital role to accomplish the computation tasks on-behalf IoT devices by offloading data from IoT nodes to nearby flying UAV [7, 17]. As well, the effective cooperation between UAVs and IoT devices to processing and offloading data can be leveraged in real-time. Thus, the flying fog computing based on UAV-MEC can reduce the execution time delay of the IoT devices, by offloading data to be processing (IoT device to nearby UAV, instead of IoT device to a far-away base station). This extends battery life [8]. Furthermore, UAVs can be used in various positions; they can carry flexible loads, measure and provide analytics about anything anywhere and at any time. The significant aspects that cooperation of UAVs and IoT have are represented by the better connectivity and delivery of high QoS as well as lower prices. The UAV-based MEC is equipment onboard devices such as memory, digital cameras, sensors, communication technologies, and actuators [18].

2. Related works

This part highlights the most relevant works that examined cooperation UAV and IoT devices in many applications. The authors in the study [9] survey the applications and techniques of drones and IoT collaboration, which have been recently proposed in order to augment the smartness of cities. The authors highlight in a comprehensive manner, the recent and current research on drone and IoT collaboration to improve the real-time application.

In the [10] the researchers introduced UAV-enabled intelligent transportation for a smart city. They investigated the potential challenges and applications for UAV enabled intelligent transportation for next generation smart cities.

Furthermore, the author of [11] addressed drone architecture as a method of delivering IoT services through a drone. The authors investigated employing RFID-equipped drones (Radio Frequency Identification), together with cameras and sensors for data collection.

The authors of [12] described the data gathering from IoT devices by using swarm of UAVs for the transmission power to be minimized from IoT devices. It was shown that each UAV delivers services on the ground to IoT cluster devices by considering the mobility of IoT devices in smart cities.

The hierarchical structure based on the collaboration between associated wireless sensors and UAVs in [13] presented crop monitoring in (PA) or precision agriculture. The authors demonstrated that the collaboration in such specific applications is an efficient solution for control, collecting data, and analysis by integrating UAVs with IoT and ground sensors. The effective management of network load and latency through optimized routes of UAV and in-situ data processing has significant benefits not only in online data collection but also relaying the data to a central monitoring point. The Authors in [14] used edge computing paradigm for smart agriculture to gathering data, exploiting tasks, and the prevalent issue of internet access.

3. System model and scenario

The proposed system model consists of a set of IoT nodes distributed in the smart agriculture that generate data and need to be processing. Also, the system has two flying UAVs one of them is UAV-MEC equipped with mobile computing server, as well as the remote base station provided by edge computing server as in the figure 1. The data will be processing either at nearby IoT nodes by flying fog edge computing server UAV-MEC or remotely at central edge cloud computing server. For first scenario, the flying fog mobile edge computing system, a UAV as MEC has been used, where the data will be offloaded from IoT nodes to nearby UAV-MEC which equipped with a computation resources, it has ability to store, processing and analyze data [19, 20]. The second scenario is remotely computing system, where the UAV as relay has been used to transfer data from IoT nodes to central edge cloud computing server via a wireless channel as shown in figure 1.

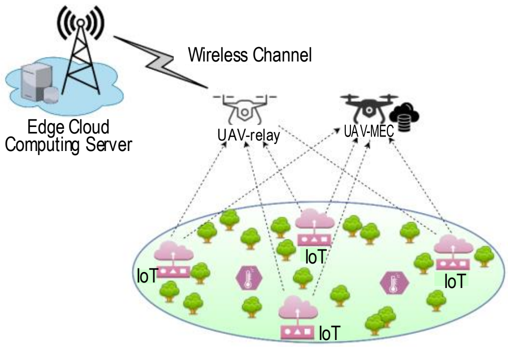

Fig. 1. System Model

The IoT nodes generates N independent tasks of computation that need to be processed. To accomplish the task, the data are offloaded and processed either at UAV-MEC when a binary computation offloading decision α_i is '1' or remotely at central edge cloud server by transfer tasks via UAV-relay when a binary computation offloading decision α_i is '0':

$$\alpha_i = \begin{cases} 1 & \text{at UAV} - \text{MEC} \\ 0 & \text{at edge cloud server} \end{cases}.$$

The following equation calculates the maximum rate of uplink data where the data of computation task are transmitted over the wireless channel [15]:

$$D_{\mathrm{IoT,UAV}} = w * \log_2\left(1 + \frac{P_{\mathrm{IoT,UAV}} G_{\mathrm{IoT,UAV}}}{\sigma\, w}\right), \qquad (1)$$

where, w represents the channel bandwidth; $G_{\mathrm{IoT,UAV}}$ is the channel gain between IoT node and UAV and edge cloud server; $P_{\mathrm{IoT,UAV}}$ is the UAV transmission power and IoT device, and σ is the density of noise power.

3.1. Computation model

This subsection presents the computation offloading model. First, the IoT nodes has N independent tasks of computation requiring completion. A tuple $\{S_i, C_i, T_i^{\mathrm{constraint}}\}$ represents the task required for each computation task i, where S_i is the size of data required to be transmitted, C_i is the total number of CPU cycles and $T_i^{\mathrm{constraint}}$ is the deadline required for task i to be completed.

Flying fog computing

In flying fog computing case, where the computation task i is offloaded and processed at UAV-MEC. The IoT nodes looks for UAV-MEC to check availability of resources to perform the task or not.

The transmission delay of computation task i from IoT node to UAV-MEC can be expressed as:

$$T_{\mathrm{IoT-UAV}}^{\mathrm{trans}} = \frac{S_i}{D_{\mathrm{IoT}}}, \qquad (2)$$

and the processing delay of computation task i in the UAV-MEC can be formulated by the following equation:

$$T_{\mathrm{UAV-MEC}}^{\mathrm{process}} = \frac{C_i}{F_{\mathrm{UAV}}}, \qquad (3)$$

where F_{UAV} is the computational capability of UAV-MEC, from (2) and (3) the total processing delay at UAV-MEC can be calculated as:

$$T_{\mathrm{UAV-MEC}}^{\mathrm{total}} = T_{\mathrm{IoT-UAV}}^{\mathrm{trans}} + T_{\mathrm{UAV-MEC}}^{\mathrm{process}}, \qquad (4)$$

$$T_{\mathrm{UAV-MEC}}^{\mathrm{total}} = \frac{S_i}{D_{\mathrm{IoT}}} + \frac{C_i}{F_{\mathrm{UAV}}}. \qquad (5)$$

Edge-cloud server computing

In edge-cloud server computing case, where the computation task i of IoT nodes will be transmitted to edge cloud server via UAV-relay and will be processed there. The transmission delay from UAV-relay to edge cloud server of computation task i of IoT node can be expressed as:

$$T_{\mathrm{UAV-server}}^{\mathrm{trans}} = \frac{S_i}{\mathrm{D_{UAV}}}. \qquad (6)$$

The processing delay of computation task i of IoT node at edge cloud server can be expressed as:

$$T_{\mathrm{server}}^{\mathrm{process}} = \frac{C_i}{F_{\mathrm{server}}}, \qquad (7)$$

where, F_{server} is the computational capability of edge cloud server.

Last, the total computation for transmission and processing delay at edge cloud server can be calculated by summation (2), (6) and (7):

$$T_{\mathrm{server}}^{\mathrm{total}} = T_{\mathrm{IoT-UAV}}^{\mathrm{trans}} + T_{\mathrm{UAV-server}}^{\mathrm{trans}} + T_{\mathrm{server}}^{\mathrm{process}}, \qquad (8)$$

$$T_{\mathrm{server}}^{\mathrm{total}} = \frac{S_i}{D_{\mathrm{IoT}}} + \frac{S_i}{D_{\mathrm{UAV}}} + \frac{C_i}{F_{\mathrm{server}}}. \qquad (9)$$

The total overhead delay for processing the computation task i can be expressed as:

$$T_i^{\mathrm{total}} = \alpha_i T_{\mathrm{UAV-MEC}}^{\mathrm{total}} + (1 - \alpha_i) T_{\mathrm{server}}^{\mathrm{total}}. \qquad (10)$$

3.2. Problem statement

This section examines the achieving efficient delay computation offloading based on flying fog computing system for smart agriculture.

The issue of computation offloading is formulated as the following constrained optimization problem:

$$\min \sum_{i=1}^{N} T_i^{\text{total}}, \qquad (11)$$

$$\text{s.t} \quad T_i^{\text{total}} \leq T_i^{\text{constraint}} \quad C1$$

$$\alpha_i \in \{0,1\} \quad C2$$

The aim of this study is minimizing the weighted delaying sum by distributing the task offloading. The constraints C1 represents time consumption upper bounds. Constraint C2 is the guarantee that the variables of offloading decisions are binary values.

4. Computation offloading algorithm

The computation flying fog computing offloading algorithm in this paper based on "Dynamic Programming with Hamming Distance Termination (DPH) algorithm" [16]. The algorithm provides inclusive process to find the decisions of optimal computation offloading of flying fog computing system. Initially, The IoT nodes offloads the task *i* to nearby UAV-MEC when $\alpha_i = 1$ or to the edge-cloud server when $\alpha_i = 0$. Dynamic programming is the basis of the proposed algorithm is based on by using $N \times N$ table (where N is the number of tasks that need to be processed). The table is used to store a bit stream to ensure which task will be processed nearby at UAV-MEC and which tasks will be executed remotely at edge-cloud server. In the table, the random bit streams that are generated are filled as ones (1s) in the following horizontal cell. The zeros (0s) are filled in the following vertical cell. The first cell is empty all the time. When the first bit is 1, then the starting cell is (1, 2). When the first bit is 0, then the starting cell is (2, 1). To illustrate the process of filling in the table the random bit stream generated, let us propose that $N = 8$, the first random α_i bit stream is 00110100 (red bits), and the second random bit stream is 10101101 (black bits). Then (2, 1) is the first stream starting cell where the first bit was 0. On the other hand, (1, 2) is the second stream starting cell as long as the first bit is 1. By following this rule to fill the tables, the resulting stream as shown in the table 1.

TABLE.1 Random Bit Stream

	1						
0	0	1					
0	1	1/0	1	1			
		0	1	0	1		
			0				
			0				

From the table, we calculate the delay of each task by each cell has 0s for flying fog computing case and each cell has 1s for edge-cloud server computing case. The computation offloading algorithm proposed in this paper is shown below.

The Computation Flying Fog Offloading Algorithm Based on Dynamic Programing Tables

1. Initialize Time matrixes and set the Completion deadline ($T_i^{constraint}$) and Transmission Rate
2. generate a task (randomly)
3. Loop iteration
4. generate a random bit stream
5. calculate delay for tasks of IoT nodes (at UAV-MEC, at edge-cloud server)
6. check the first bit to specify the starting cell in the first table
8. loop i to N-1
9. if bit(i) == 1 in the table (UAV-MEC)
10. regenerate random bit (0 or 1)
11. end if
12. Put each bit of the bit stream in the correct position in table
13. if this specific cell in tables is visited before compare the new Total delay of this cell with the previous one
14. if the new Total delay of the cell is less than the previous one
15. Replace the total delay of this cell with the new calculated amounts.
16. Calculate the delay of the remaining bits of the new bit stream
17. else
18. Keep the previous total delay in the cell.
29. Calculate the delay of the remaining cells of the new stream based on the existing amount of this cell
20. end if
21. end if
22. end Loop
23. if Number of bits in tables = N & Ttotal < $T_i^{constraint}$ & hamming distance criterion is met
24. return Ttotal
25. end if
26. end Loop

5. Simulation setup and results

The simulation of our work was implemented by Matlab environment. The parameters that applied in this work it shown in the table 2.

TABLE 2. Simulation Parameters

Parameter	Value
Number of tasks N	15
Data size S_i	10–30 MB
CPU cycles C_i	1900 Cycle/s
Time Constraint $T_i^{\text{constraint}}$	0,002 s
Transmission data rate D_{IoT}, D_{UAV}	3–9 Mbps
Computation capacity of UAV-MEC (F_{UAV})	500 MHz
Computation capacity of edge-cloud server (F_{server})	1000 GHz

The number of tasks is set as $N = 15$ and 5 as the number of IoT nodes. The computational capabilities of UAV-MEC and edge-cloud server are 500 MHz and 1000 GHz, respectively. Hence, data size augmented randomly from 10 to 30 Megabyte. The CPU cycles needed to perform the task *i* is 1900 cycle/s. According to the distances, the rates of transmission data also changed randomly 3 to 9 Mbps, which means that shorter distances mean bigger rate of transmission.

Figure 2 the delay versus transmission data rate, as shown in the figure, the delay decreases whenever transmission data rate increase when IoT nodes offloads all task to UAV-MEC or to edge-cloud server. As well as, in the Figure 3 the delay versus computational capability in case flying fog computing and edge-cloud server computing. The figure shows that the total delay decreased when increasing the computational capability when IoT nodes offloads the tasks to UAV-MEC or to edge-cloud server.

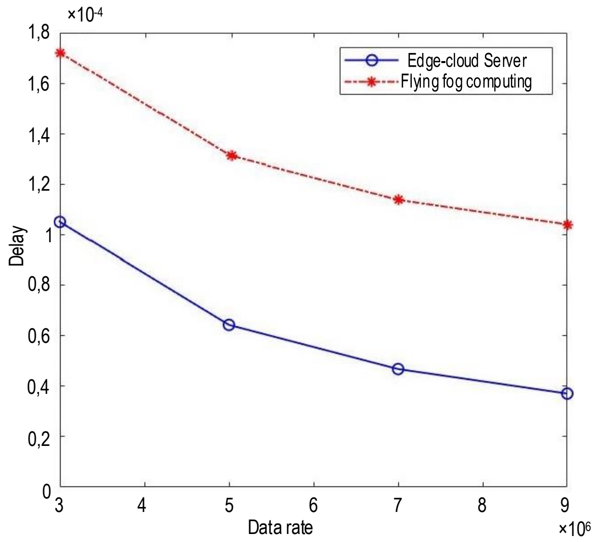

Fig. 2. Delay VS Data Rate

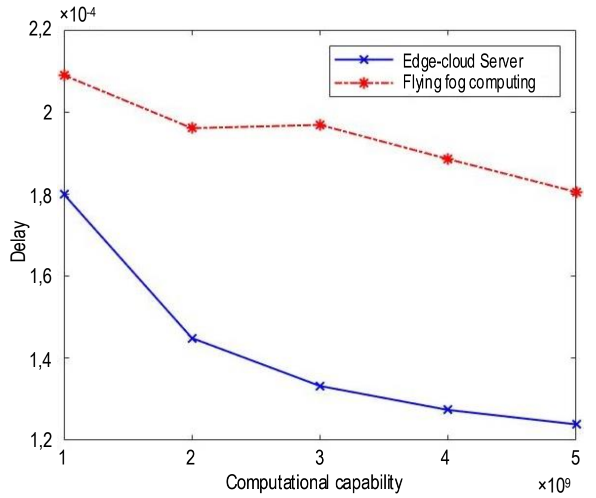

Fig. 3. Delay VS Computational Capability

In the figures 4 and 5, the delay in both figures increased linearly with increase the data size and number of tasks that generated from IoT nodes. As shown in the figure, the total delay is maximized when the tasks are offloaded and executed at UAV-MEC or remotely at edge-cloud server. The delay in case of flying fog computing much higher than the delay in case of edge-cloud server because of the computation capacity of edge-cloud server much higher than the computation capacity of UAV-MEC.

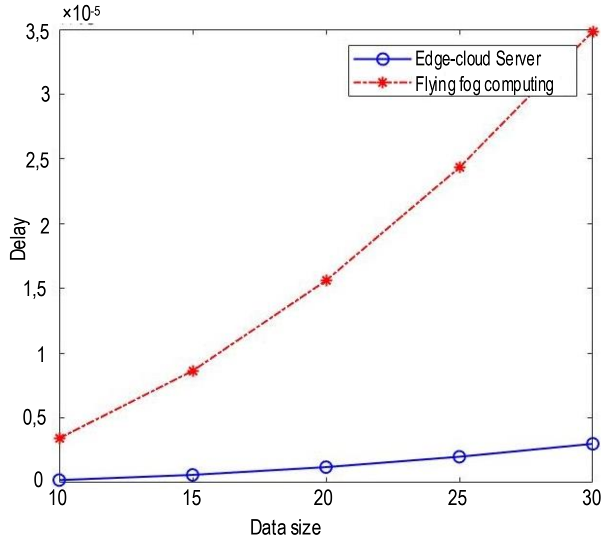

Fig. 4. Delay VS Data Size

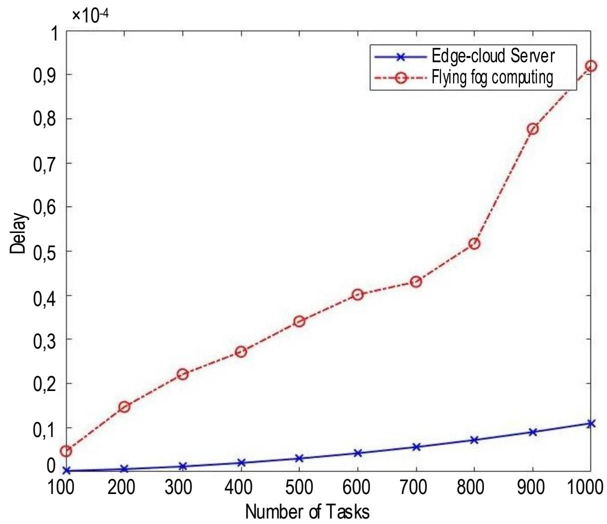

Fig. 5. Delay VS Number of Tasks

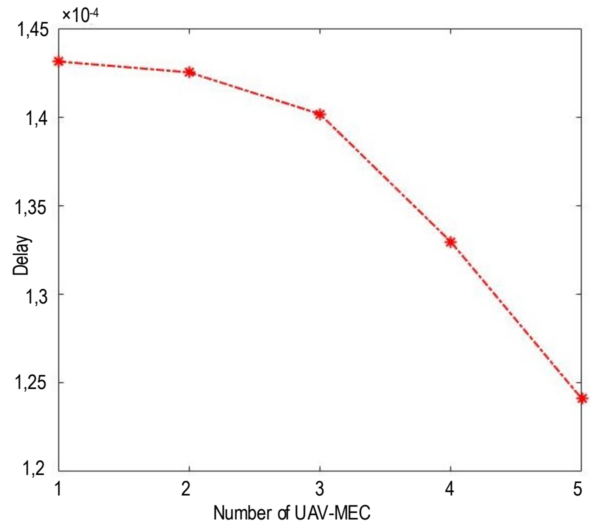

Fig. 6. Delay VS Number of UAV-MEC

Accordingly, to reduce the delay of computation task need to increase either the computational capacity of UAV-MEC or increase the number of UAV-MEC as shown in the figure 6.

Conclusion

In this paper, presented a computation offloading model based on flying fog mobile edge computing to assisting IoT devices in smart agriculture by using UAV mounted with computation resources, as well as remote edge cloud server. The processing and the services will be provided to the IoT devices either by nearby UAV-MEC or by remote edge server. The evolving of edge computing brings computing to the edge of the network near data sources. The UAV and edge computing providing a promising solution for efficient intelligent IoT applications. We have formulated a delay-efficient computation offloading problem. Then we are proposed algorithm to solve the formulated problem, it was "Dynamic Programming with Hamming Distance Termination (DPH) algorithm" which showed good results to solve the proposed problem and realize a computation offloading tasks. The objective of work is to minimize the total delay to processing the data of IoT devices. In conclude, the results showed that the greater data rate, and greater the computational capability in both UAV-MEC and remote edge cloud server, the less delay to accomplish the tasks.

References

1. Naqvi S.A.R., Hassan S.A., Pervaiz, Ni Q. Drone-Aided Communication as a Key Enabler for 5G and Resilient Public Safety Networks. *IEEE Communications Magazine*. 2018;56(1):36–42. DOI:10.1109/MCOM.2017.1700451

2. Zhang M., Su C., Liu Y., Hu M., Zhu Y. Unmanned Aerial Vehicle Route Planning in the Presence of a threat Environment Based on a Virtual Globe Platform. *ISPRS International Journal of Geo-Information*. 2016;5(10):184. DOI:10.3390/ijgi5100184

3. Mahmud I., Cho Y.-Z. Adaptive Hello Interval in FANET Routing Protocols for Green UAVs. *IEEE Access*. 2019;7: 63004–63015. DOI:10.1109/ACCESS.2019.2917075

4. Cao X., Yang P., Alzenad M., Xi X., Wu D., Yanikomeroglu H. Airborne Communication Networks: A Survey. *IEEE Journal on Selected Areas in Communications*. 2018;36(9):1907–1926. DOI:10.1109/JSAC.2018.2864423

5. Mozaffari M., Saad W., Bennis M., Debbah M. Mobile Unmanned Aerial Vehicles (UAVs) for Energy-Efficient Internet of Things Communications. *IEEE Transactions on Wireless Communications.* 2017;16(11):7574–7589. DOI:10.1109/TWC.2017.2751045

6. Alsamhi S.H., Ma O., Ansari M.S., Almalki F.A. Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities. *IEEE Access.* 2019;7:128125–128152. DOI:10.1109/ACCESS.2019.2934998

7. Alsamhi S.H., Ma O., Ansari M.S., Meng Q. Greening Internet of Things for Smart Everythings with a Green-Environment Life: A Survey and Future Prospects. 2018. DOI:10.48550/arXiv.1805.00844

8. Alsamhi S.H., Ma O., Ansari M.S., Gupta S.K. Collaboration of Drone and Internet of Public Safety Things in Smart Cities: An Overview of QoS and Network Performance Optimization. *Drones.* 2019;3(1):13. DOI:10.3390/drones3010013

9. Alsamhi S.H., Ma O., Ansari M.S., Almalki F.A. Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities. *IEEE Access.* 2019;7:128125–128152. DOI:10.1109/ACCESS.2019.2934998

10. Menouar H., Guvenc I., Akkaya K., Uluagac A. S., Kadri A., Tuncer A. UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges. *IEEE Communications Magazine.* 2017;55(3):22–28. DOI:10.1109/MCOM.2017.1600238CM

11. Motlagh N.H., Taleb T., Arouk O. Low-Altitude Unmanned Aerial Vehicles-Based Internet of Things Services: Comprehensive Survey and Future Perspectives. *IEEE Internet Things Journal.* 2016;3(6):899–922. DOI:10.1109/JIOT.2016.2612119

12. Mohammad M., Saad W., Bennis M., Debbah M. Mobile Internet of Things: Can UAVs Provide an Energy-Efficient Mobile Architecture? *Proceedings of the Global Communications Conference, GLOBECOM, 04–08 December 2016, Washington, USA*. IEEE; 2016. DOI:10.1109/GLOCOM.2016.7841993

13. Chen X., Shi Q., Yang L., Xu J. ThriftyEdge: Resource-Efficient Edge Computing for Intelligent IoT Applications. *IEEE Network.* 2018;32(1):61–65. DOI:10.1109/MNET.2018.1700145

14. Li X., Ma Z., Zheng J., Liu Y., Zhu L., Zhou N. An Effective Edge-Assisted Data Collection Approach for Critical Events in the SDWSN-Based Agricultural Internet of Things. *Electronics.* 2020;9(6):907. DOI:10.3390/electronics9060907

15. Alzaghir A., Koucheryavy A. Multi Task Multi-UAV Computation Offloading Enabled Mobile Edge Computing Systems. *Proceedings of the 24th International Conference on Distributed Computer and Communication Networks, DCCN, 20–24 September 2021, Moscow, Russia. Communications in Computer and Information Science, vol.1552*. Cham: Springer; 2021. DOI:10.1007/978-3-030-97110-6_1

16. Shahzad H., Szymanski T.H. A dynamic programming offloading algorithm for mobile cloud computing. *Proceedings of the Canadian Conference on Electrical and Computer Engineering, CCECE, 15–18 May 2016, Vancouver, Canada*. IEEE; 2016. DOI:10.1109/CCECE.2016.7726790

17. Koucheryavy A.E., Vladyko A.G., Kirichek R.V. Flying Ubiquitous Sensor Networks – A New Application of Internet of Things. *Proceedings of the IV International Conference on Infotelecommunications in Science and Education, 03–04 March 2015, St. Petersburg, Russia.* St. Petersburg: The Bonch-Bruevich Saint-Petersburg State University of Telecommunications Publ.; 2015. p.17–22. (in Russ.)

18. Vyrelkin A., Koucheryavy A. Using of Unmanned Aerial Vehicles for Solving the Problems of the Smart City. *Telecom IT.* 2017;5(1): 105–113. (in Russ.)

19. Alzaghir A.A., Koucheryavy A.E. Offloading Traffic When Integrating UAVs and Edge Computing Systems. *SPbNTORES: Proceedings of the Annual Scientific and Technical Conference*. 2022;1(77):115-116. (in Russ.)

20. Filimonova M.I., Alzagir A.A., Muthanna A.S.A. Development of Methods of UAV Application to Ensure Stability of Communication Networks 2030. *SPbNTORES: Proceedings of the Annual Scientific and Technical Conference*. 2020;1(75):164–165. (in Russ.)

Список источников

1. Naqvi S.A.R., Hassan S.A., Pervaiz H., Ni Q. Drone-Aided Communication as a Key Enabler for 5G and Resilient Public Safety Networks // IEEE Communications Magazine. 2018. Vol. 56. Iss. 1. PP. 36–42. DOI:10.1109/MCOM.2017.1700451

2. Zhang M., Su C., Liu Y., Hu M., Zhu Y. Unmanned Aerial Vehicle Route Planning in the Presence of a threat Environment Based on a Virtual Globe Platform // ISPRS International Journal of Geo-Information. 2016. Vol. 5. Iss. 10. P. 184. DOI:10.3390/ijgi5100184

3. Mahmud I., Cho Y.-Z. Adaptive Hello Interval in FANET Routing Protocols for Green UAVs // IEEE Access. 2019. Vol. 7. PP. 63004–63015. DOI:10.1109/ACCESS.2019.2917075

4. Cao X., Yang P., Alzenad M., Xi X., Wu D., Yanikomeroglu H. Airborne Communication Networks: A Survey // IEEE Journal on Selected Areas in Communications. 2018. Vol. 36. Iss. 9. PP. 1907–1926. DOI:10.1109/JSAC.2018.2864423

5. Mozaffari M., Saad W., Bennis M., Debbah M. Mobile Unmanned Aerial Vehicles (UAVs) for Energy-Efficient Internet of Things Communications // IEEE Transactions on Wireless Communications. 2017. Vol. 16. Iss. 11. PP. 7574–7589. DOI:10.1109/TWC.2017.2751045

6. Alsamhi S.H., Ma O., Ansari M.S., Almalki F.A. Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities // IEEE Access. 2019. Vol. 7. PP. 128125–128152. DOI:10.1109/ACCESS.2019.2934998

7. Alsamhi S.H., Ma O., Ansari M.S., Meng Q. Greening Internet of Things for Smart Everythings with a Green-Environment Life: A Survey and Future Prospects. 2018. DOI:10.48550/arXiv.1805.00844

8. Alsamhi S.H., Ma O., Ansari M.S., Gupta S.K. Collaboration of Drone and Internet of Public Safety Things in Smart Cities: An Overview of QoS and Network Performance Optimization // Drones. 2019. Vol. 3. Iss. 1. P. 13. DOI:10.3390/drones3010013

9. Alsamhi S.H., Ma O., Ansari M.S., Almalki F.A. Survey on Collaborative Smart Drones and Internet of Things for Improving Smartness of Smart Cities // IEEE Access. 2019. Vol. 7. PP. 128125–128152. DOI:10.1109/ACCESS.2019.2934998

10. Menouar H., Guvenc I., Akkaya K., Uluagac A. S., Kadri A., Tuncer A. UAV-Enabled Intelligent Transportation Systems for the Smart City: Applications and Challenges // IEEE Communications Magazine. 2017. Vol. 55. Iss. 3. PP. 22–28. DOI:10.1109/MCOM.2017.1600238CM

11. Motlagh N.H., Taleb T., Arouk O. Low-Altitude Unmanned Aerial Vehicles-Based Internet of Things Services: Comprehensive Survey and Future Perspectives // IEEE Internet Things Journal. 2016. Vol. 3. Iss. 6. PP. 899–922. DOI:10.1109/JIOT.2016.2612119

12. Mohammad M., Saad W., Bennis M., Debbah M. Mobile Internet of Things: Can UAVs Provide an Energy-Efficient Mobile Architecture? // Proceedings of the Global Communications Conference (GLOBECOM, Washington, USA, 04–08 December 2016). IEEE, 2016. DOI:10.1109/GLOCOM.2016.7841993

13. Chen X., Shi Q., Yang L., Xu J. ThriftyEdge: Resource-Efficient Edge Computing for Intelligent IoT Applications // IEEE Network. 2018. Vol. 32. Iss. 1. PP. 61–65. DOI:10.1109/MNET.2018.1700145

14. Li X., Ma Z., Zheng J., Liu Y., Zhu L., Zhou N. An Effective Edge-Assisted Data Collection Approach for Critical Events in the SDWSN-Based Agricultural Internet of Things // Electronics. 2020. Vol. 9. Iss. 6. P. 907. DOI:10.3390/electronics9060907

15. Alzaghir A., Koucheryavy A. Multi Task Multi-UAV Computation Offloading Enabled Mobile Edge Computing Systems // Proceedings of the 24th International Conference on Distributed Computer and Communication Networks (DCCN, Moscow, Russia, 20–24 September 2021). Communications in Computer and Information Science. Vol. 1552. Cham: Springer, 2021. DOI:10.1007/978-3-030-97110-6_1

16. Shahzad H., Szymanski T.H. A dynamic programming offloading algorithm for mobile cloud computing // Proceedings of the Canadian Conference on Electrical and Computer Engineering (CCECE, Vancouver, Canada, 15–18 May 2016). IEEE, 2016. DOI:10.1109/CCECE.2016.7726790

17. Кучерявый А.Е., Владыко А.Г., Киричек Р.В. Летающие сенсорные сети-новое приложение интернета вещей // IV Международная научно-техническая и научно-методическая конференция «Актуальные проблемы инфотелекоммуникаций в науке и образовании» (Санкт-Петербург, Россия, 03–04 марта 2015). Сборник научных статей. СПб.: СПбГУТ, 2015. С. 17–22.

18. Вырелкин А.Д., Кучерявый А.Е. Использование беспилотных летательных аппаратов для решения задач «умного города» // Информационные технологии и телекоммуникации. 2017. Т. 5. № 1. С. 105–113.

19. Алзагир А.А., Кучерявый А.Е. Разгрузка трафика при интеграции БПЛА и граничных вычислительных систем // СПбНТОРЭС: труды ежегодной НТК. 2022. № 1(77). С. 115–116.

20. Филимонова М.И., Алзагир А.А., Мутханна А.С.А. Разработка методов применения БПЛА для обеспечения устойчивости сетей связи 2030 // СПбНТОРЭС: труды ежегодной НТК. 2020. № 1(75). С. 164–165.

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