UAV Assisted Wireless Network

Sihao Teng

1The University of Bristol, School of Engineering, Bristol, United Kingdom, BS14TR
*Corresponding author’s e-mail: tengsihao2019@163.com

Abstract. With the increasing demand of social network service, the unmanned aerial vehicle has been used as a base station to assist terrestrial base station to improve wireless network performance. UAV base station provides high efficiency and wider data transmitting range due to the small size and flexibility of UAV. However, UAV wireless network faces few challenges. Energy efficiency is hard to achieve due to small battery capacity. The base station performance is also very important. It can be determined by aircraft’s flying stability, the performance of air to ground communication and the limitation of wireless coverage of UAV. In order to achieve optimal UAV deployment, improving deployment delay, communication coverage and UAV number limitation are important. Trajectory optimizing problems also need to be considered. This article analyzes UAV assisted wireless networks through investigating UAV energy efficiency, UAV aided network performance, optimal deployment methods and flight trajectory. It is shown that energy efficiency can be optimized by applying LoS based channel in UAV trajectory planning. And inequality iteration algorithm proposed by former researchers is used to determine optimal flight trajectory. This method is efficient because of cellular network’s interference-free ability. As for performance, channel selection methods are used to reduce overflow rate and boost data-received size. These methods are analyzed and proved to be effective for improving UAV aided wireless network performance.

1. Introduction

Unmanned Aerial Vehicle(UAV) has been widely used in military and civil domains in recent years. Due to its small size and flexibility, UAV can be used for battle field reconnaissance, power grid inspection, target recognition. Nowadays, with the increasing demands of social network services, and the popularization of 5G networks, implementing a mobile 5G network by using UAV has attracted great attention. On the one hand, UAV base station can be used to assist traditional communication network enables data to transmit for a wider range. Relay transmission technology is more efficient and cost effective than building an antenna. On the other hand, in remote areas, using UAV can save the budget for constructing network stations, and UAV base stations can be moved and reconstructed easily to prevent waste of resources. UAV provides cost-effective deployment and fast network system reconfiguration compared with the terrestrial base station. Reliable connectivity with low latency is also provided.

However, UAV aided wireless network faces several challenges. First of all, the most obvious issue is that UAV has limited battery capacity. Improving the energy efficiency of UAV network is a challenge. Secondly, UAV-based base station performance is also very important. It can be determined by aircraft’s flying stability, the performance of air to ground communication and the limitation of wireless coverage of UAV. Thirdly, UAV deployment is challenging due to its unique characteristics. Deployment delay, communication coverage and UAV number limitation are crucial problems that need to be addressed. Lastly, trajectory optimizing problems also need to be considered. It can be
improved by analyzing ground users’ moving pattern, and detecting the surrounding environment to make the optimal path planning.

This article analyzes UAV aided wireless networks from four different perspectives, which are energy efficiency, performance, UAV deployment and trajectory planning. In section II, some derived formulations and established models proposed by former researchers are presented along with the evaluation of each research method. The conclusion and open research issues are presented in section III.

2. UAV aided wireless network analysis

2.1. Energy efficiency of UAV

In a UAV-based communication network, efficient battery energy usage is required to providing a high quality of service (QoS) and the energy efficiency problem is quite challenging. UAV battery energy is drained quickly when used for communicating circuitry, which leads to a decrease in flight time. In order to address this problem, efficient algorithms are proposed to satisfy the transmission power requirements and connectivity quality. Since UAV network and ground network are rarely used together to serve network users and a mobile node commonly corresponds to a single base station, which leads to the poor energy efficiency of UAV network. A weighted power allocation model [1] is proposed. Signal to interference and noise ratio (SINR) level at mobile node received from nearby UAV base station (UBS) and terrestrial base station (TBS) is measured by using the general SINR level equation (1), where $P_{jn}$ represents power transmitted from base station to user, $h_{jn}$ represents channel gain, $W$ represents bandwidth, and $\sigma$ represents noise.

$$SINR_{jn} = \frac{P_{jn} h_{jn}}{1 + \sum_{j' \in J \setminus \{j\}} P_{j'n} h_{j'n} + W \sigma}$$  \hspace{1cm} (1)

The weights proportion between UBS and TBS is calculated from their corresponding SINR level using equation (2).

$$\theta_n = \frac{SINR_{un}}{SINR_{un} + SINR_{tn}} \hspace{1cm} (2)$$

By changing the number of mobile nodes in the system, energy consumption of network increases as the number of nodes increases. However, UAV network consume less energy compared with a terrestrial network, and as the number of mobile nodes increases, difference between their energy consumption becomes larger. So using a higher proportion of UAV network when serving mobile nodes increases overall energy efficiency, because of the better utilization of line of sight communication links.

Optimizing UAV flight trajectory with a line of sight (LoS) and non-line of sight (NLoS) based channel and improving UAV propulsion energy consumption can maximize the energy efficiency of UAV network [2]. Since energy consumption of UAV propulsion is determined by UAV moving speed and trajectory, trajectory radius and transmitting power of aircraft are key elements for improving energy efficiency. For different flight duration, UAV hovering time and moving trajectory are different. If UAV flight time increases, it could cover larger territory and provide services to more users, because the hovering path is larger. UAV coverage of territory becomes more efficient with limitation of UAV altitude, and setting hovering path close to ground users provides better performance in energy consumption with less flight duration and longer hovering path.

Under the newly formed network of re-configured UAV, a sub-net is proposed to save energy consumption. Service area, capacity demand, flow demand and coverage area are key components used for adjusting time intervals of power supply in sub-net.[4] Energy efficiency is achieved by turning high power-consuming node to low power mode or turning it off. Moreover, scheduling sleep activity with various data frequencies and signal flows can improve energy efficiency by controlling
wake up time periods of different nodes. These nodes are activated in order and are based on the duty cycle. [5] When one node is activated, it sends a signal to the next node to wake it, otherwise it remains in sleeping mode.

2.2. UAV base station performance
Improving flight stability is a basic method for developing the overall performance of UAV. During the flight, UAV might face lots of interference coming from surrounding electromagnetic fields. Some might cause errors in default flight trajectory or lead to poor flight stability. Adjusting flight trajectory based on aircraft attitude information leads to improvements in flight performance, and it requires accurate measurement and control command execution to complete operation. A control system based on neural network training is proposed.[6] It is constructed with uncertain parameters. The state feedback auto-adjusting method makes aircraft change their actuator input and flight attitude. It trains UAV to work under interference and modeling errors.

![Figure 1 Smith control structure](image)

Reducing the center of gravity height of UAV helps to reduce the time delay of flight attitude. Due to the adjustment of UAV speed center, the optimal control is realized. Attitude adjustment delay is decreased by using improved Smith UAV controller (shown in Figure 1). This algorithm improves the real-time command sending and receiving performance, so that great flight stability can be achieved.

Improving frequency utilization and making efficient use of rarely used frequency channels could effectively reduce transmission time and improve UAV performance. Real-time monitoring and video transmission technology can reduce transmission time by half and optimize frequency utilization. Receiving and transmitting signals at different frequency bands could make efficient use of many untapped channels. However, buffer overflow might be a problem when using relay UAV, it degrades the video quality received at base station. The overflow occurred at buffer is mainly due to the difference in transmitting, receiving rate and start timing errors of transmission. Buffer overflow can be efficiently avoided by controlling transmission starting time as relay UAV starts to transfer signal to the ground station after it finished data receiving.[7] Selecting transmitting and receiving channels can also reduce the overflow rate. For the amount of data received at a ground station, the situation of no congestion difference between transmitting and receiving channels outperforms the situation when there is a difference in congestion between links. So selecting appropriate channels to balance sending and receiving rate and controlling transmission starting time are both effective to boost receiving data size and improve the performance of UAV real time video transmission.

2.3. UAV deployment
To solve the open problem of UAV deployment, due to the unique characteristics of UAV, a new UAV optimized placement solution is needed. Joint optimization of UAV deployment and transmitting bandwidth allocation could realize low delay communication. This leads to a reduction in user downlink transmission delay. Due to the limitation of UAV base station number, user location and available total bandwidth, finding the optimal location and transmission bandwidth of UAV base station is crucial. The UB-K-Means algorithm [8] considers both user location and bandwidth requirements for user and base station. The difference between UAV carried bandwidth and bandwidth required by user is controlled. However, interference between UAV and flight altitude control has not been considered, and LoS link is only one of the factors that determine wireless communication between user and UAV.
Fast deployment methods should also be considered. When UAV providing service to ground users, distance to the final working position, moving speed and experience of deployment delay determine deployment efficiency. Total deployment delay is influenced by the highest and lowest possible flight altitude. The ratio of maximum flight altitude and minimum flight altitude decrease leads to a drop in deployment delay. With optimal development in UAV moving speed, traveling distance, coverage radius and flight altitude, fast UAV deployment can be achieved. UAV bandwidth resources shortage leads to interference between UAV, so orthogonal channels cannot be assigned to a large number of UAV.

The coverage performance of UAV base stations serving ground users is affected by obstacles. Optimization of the layout of UAV base station to avoid them from colliding with each other or other obstacles improve its coverage performance. This is particularly useful for UAV operating with millimeter-wave (mmW) technology. A 3D sensing antenna array is introduced.[9] Sending an alerting signal and performing an evasion operation to UAV control board if UAV radar detects obstacles within a reachable range. Based on the detected obstacle and user locations, optimized UAV placement could be achieved, and improve the total coverage of UAV base station.

2.4. Trajectory
UAV trajectory optimization is quite challenging despite all the research that has been done on it. A desired trajectory of all the UAVs in a communication system is proposed with a mathematical method. [10] The total traveling distance of all UAV nodes is effectively reduced when the specified location is reached by the leading UAV. The decrease in traveling distance saves UAV battery consumption. The proposed method can calculate the desired trajectory involving all the obstacles detected. So UAV could operate in remote forests and construction sites, even there are lots of obstacles.

Inequality iteration algorithm [11] is proposed to determine the shortest flight trajectory from the starting position to the ending position providing constant flight altitude and moving speed of the aircraft, and it is applied under the restraint of cellular network connection. The cellular network has a strong ability to avoid interference, which provides a good environment for inequality iteration algorithms because the interference of different UAV channels has been effectively addressed. As the number of iterations increases, higher quality of trajectory solution is provided. This algorithm is also used when there are multiple UAV. It enables multiple aircraft to move between various initial positions and stop positions without any trajectory overlapping only if their flight altitudes are different.

For long-term UAV content coverage, multi UAV trajectory planning is necessary, because UAV battery is limited. However, it is challenging for distributed multi UAV trajectory planning to implement in an unknown environment. The location of ground user and channel state information is hard to acquire in unknown environments, and these pieces of information are key elements to evaluate trajectory planning. Effective use of UAV differentiated content service is the key to multi UAV trajectory planning. When dividing the long-term operation into small individual time slots, efficiency evaluation of UAV depends on current environment state and UAV actions. In addition, multi UAV trajectory planning has two main characteristics, which are collaboration and competition among UAVs. As for collaboration, a large number of UAVs are organized into a group to provide content services to users. So differences in content service among UAVs should be considered along with trajectory design in order to achieve optimal efficiency. As for competition among UAVs, each UAV tends to increase its long-term return and this will result in degradation of system performance. Multi UAV trajectory uncertainties are formulated as two stochastic games [12] and a decentralized reinforcement learning algorithm is proposed to enable UAVs to make an independent decision on their own trajectory strategy.
3. Conclusion
UAV based wireless communication network has been comprehensively analyzed in this paper. The use of UAV in a wireless network is affected by energy consumption of battery. Using LoS and NLoS based channel reduces propulsion energy consumption. By controlling the proportion of used UAV base station and terrestrial base station make efficient use of energy because of efficient use of LoS communication links. However, the balance between energy consumption and performing requirements also needs to be considered. Algorithms that show good results in one aspect may not be suitable for improving the overall network energy efficiency. Selecting appropriate channels for sending and receiving data and controlling start times can boost receiving data capacity and improve real-time communication quality. Optimizing UAV deployment and bandwidth allocation strategy could minimize communication delay. Coverage performance is improved by designing an optimal UAV layout to relieve obstacle interference, while efficient deployment is determined by UAV moving speed, traveling distance, coverage radius and flight altitude. Inequality iteration algorithm is effective for determining minimal flight distance. With the popularity of 5G communication, a large number of applications based on UAV network will be implemented. Security threats caused by false information and service destruction need to be addressed properly.

Acknowledgments
Professor Stepan Lucyszyn, Mr Yihao Wu, Mrs Mandy Han offered their help for me to complete this paper. Professor Lucyszyn taught me about some radio frequency theories, so that I could begin my research. Mr Wu helped me with the outline of my paper, and he suggested a few research direction that I can focus on. Mrs Han helped me with the general structure of my article, for example, grammar correction and reference form.

References
[1] A. Manzoor, D. H. Kim and C. S. Hong, "Energy Efficient Resource Allocation in UAV-based Heterogeneous Networks," 2019 20th Asia-Pacific Network Operations and Management Symposium (APNOMS), 2019, pp. 1-4, doi: 10.23919/APNOMS.2019.8892933.
[2] S. Ahmed, M. Z. Chowdhury and Y. M. Jang, "Energy-Efficient UAV-to-User Scheduling to Maximize Throughput in Wireless Networks," in IEEE Access, vol. 8, pp. 21215-21225, 2020, doi: 10.1109/ACCESS.2020.2969357.
[3] M. N. Bashir and K. Mohamad Yusof, "Green Mesh Network of UAVs: A Survey of Energy Efficient Protocols across Physical, Data Link and Network Layers," 2019 4th MEC International Conference on Big Data and Smart City (ICBDSC), 2019, pp. 1-6, doi: 10.1109/ICBDSC.2019.8645588.
[4] A. Capone, F. Malandra and B. Sansò, "Energy Savings in Wireless Mesh Networks in a Time-Variable Context", Journal of Mobile Networks and Applications, vol. 17, no. 2, pp. 298-311, Apr 2012.
[5] Xue Yang and N. F. Vaidya, "A Wakeup Scheme for Sensor Networks: Achieving Balance between Energy Saving and End-to-end Delay", Proceedings of the 10th IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS), pp. 19-26, May 2004.
[6] L. Xinghua, "Research on UAV Time Delay Controller Based on Improved Smith Training Neural Network," 2018 IEEE International Conference of Safety Produce Informatization (IICSPI), 2018, pp. 270-275, doi: 10.1109/IICSPI.2018.8690329.
[7] A. Hanyu, Y. Kawamoto and N. Kato, "Adaptive Channel Selection and Transmission Timing Control for Simultaneous Receiving and Sending in Relay-Based UAV Network," in IEEE Transactions on Network Science and Engineering, vol. 7, no. 4, pp. 2840-2849, 1 Oct.-Dec. 2020, doi: 10.1109/TNSE.2020.2997721.
[8] H. Qu, W. Zhang, J. Zhao, Z. Luan and C. Chang, "Rapid Deployment of UAVs Based on Bandwidth Resources in Emergency Scenarios," 2020 Information Communication Technologies Conference (ICTC), 2020, pp. 86-90, doi: 10.1109/ICTC49638.2020.9123274.
[9] B. B. Tierney and C. T. Rodenbeck, "3D-Sensing MIMO Radar for UAV Formation Flight and Obstacle Avoidance," 2019 IEEE Radio and Wireless Symposium (RWS), 2019, pp. 1-3, doi: 10.1109/RWS.2019.8714287.

[10] R. d. Silva and S. Rajasinghege, "Optimal Desired Trajectories of UAVs in Private UAV Networks," 2018 International Conference on Advanced Technologies for Communications (ATC), 2018, pp. 310-314, doi: 10.1109/ATC.2018.8587422.

[11] Y. Wu, W. Yang, X. Guan and Q. Wu, "Energy-Efficient Trajectory Design for UAV-Enabled Communication Under Malicious Jamming," in IEEE Wireless Communications Letters, vol. 10, no. 2, pp. 206-210, Feb. 2021, doi: 10.1109/LWC.2020.3024548.

[12] C. Zhao, J. Liu, M. Sheng, W. Teng, Y. Zheng and J. Li, "Multi-UAV Trajectory Planning for Energy-efficient Content Coverage: A Decentralized Learning-Based Approach," in IEEE Journal on Selected Areas in Communications, doi: 10.1109/JSAC.2021.3088669.