Interference Mitigation in UAV Communications: A Review of Literature

Nolan Pettit
University of Nebraska-Lincoln
Summer REU
Lincoln, NE, USA
npettit4@huskers.unl.edu

***Abstract*—This literature review explores methods and benefits to implementing unmanned aerial vehicles (UAVs) to provide wireless communication with high resiliency. This review focuses on interference mitigation techniques that improve the connection between user equipment (UE) and base stations (BS). Various methods including multi-antenna receivers, beamforming optimization, selection combining, and maximal-ratio combining are identified, each with advantages and disadvantages.**

***Index Terms*—UAV, interference mitigation, wireless communication**

I. Introduction

As new methods for wireless communications arise, the use of UAVs has become more common. The implementation of UAVs as base stations instead of large communication towers has led to faster deployment and wider coverage. UAVs are more cost efficient and maneuverable [1]; however, interference between the aircraft and user is a common challenge. The interference that can occur between a UAV and user is difficult to mitigate, leading researchers to develop techniques to optimize the connection. Due to their increased capabilities, the UAV market is experiencing rapid growth, allowing for them to become more accessible to users [2]. They are capable of offering strong connections in congested areas such as large cities [3] or by providing crucial communication links for first responders [4]. By examining existing research in interference mitigation techniques, this review aims to identify potential methods to limit the amount of interference that occurs in UAV communication.

The rest of this review is organized into three more sections. Next, the advantages and disadvantages of using UAVs will be listed. Then, interference mitigation metrics and techniques will be discussed in three subsections. It will be broken up into "Signal-to-Interference-Plus-Noise Ratio", "Multiple Antenna Receivers", and "Beamforming". Lastly, a conclusion will summarize the contents of the literature review, and references will be organized chronologically.

II. Challenges of Using UAVs

UAVs, commonly referred to as drones, are experiencing increased applications in the modern world; however, the implementation of drones in wireless communication comes with a few difficulties such as interference, energy limitations, and scatterers. UAVs offer low cost and high maneuverability, but often lack the ability to deliver long-term communication links due to energy limitations. To combat this issue, researchers have proposed energy-aware deployment methods in which multiple UAVs are used. In this method, only one UAV is able to leave the service space at a time while surrounding UAVs are tasked with continuing the communication link. By doing this, users can be served at all times while some UAVs are recharged [5]. Secondly, it is important to optimize the flight path of drones to avoid unnecessary movements. To do this, a model using the drone's speed, acceleration, and altitude has been developed. The same group of researchers have shown that node-clustering algorithms can improve the efficiency of drones [5]. This method involves transmitting information to ground nodes, and the nodes will communicate and exchange data with each other. By doing this, UAVs would be able to administer data more effectively and potentially to a wider spread of users. Another study explores the data service that each UAV transmits and determines optimal flight paths [6]. This study performs multiple scenarios in which the amount of data being transmit and the flight path at which the drone travels are altered.

Another challenge that arises in wireless communication with drones, is the affect of scatterers on the UAV's ability to deliver reliable connections. In an urban scenario, scatterers, such as cars or buildings, have a significant impact on a UAV's ability to distribute communication services. The two ray propagation model [7] that has been developed by researchers helps determine the amount of received power that reaches a user. The received signal strength (RSS) mostly follows the two ray propagation model, but tall buildings in the urban scenario can effect this value. When the LoS is blocked, it is more difficult to have a strong received signal. When dealing with scatterers, it is important to avoid LoS blockages; however, it is sometimes unavoidable. One study was able to devise an equation to account for the path loss that occurs when the LoS is blocked:

$$P_{LoS}(\theta) = \frac{1}{(1 + a * \exp(-b(\theta - a))}, \tag{1}$$

in which θ represents the angle of elevation, and the variables a and b are modeling parameters that change depending on the environment [8]. This equation is useful, because it helps determine the amount of loss that occurs due to scatterers, ultimately giving researchers an idea of the amount of interference present.

Along with LoS issues and energy limitations, UAVs are subject to interference. This can be due to long distances between the UAV and a user, or interference can occur from inter-cell signals [9]. To limit this, methods such as beamforming (III-C) have been developed to direct a signal in the direction of a desired user. Although there are many challenges with implementing UAVs in wireless communications, new techniques and models are being created to optimize the efficiency of drones.

III. Interference Mitigation: Metrics and Techniques

A. *Signal-to-Interference-Plus-Noise Ratio*

The most common statistic for measuring interference is calculating the signal-to-interference-plus-noise ratio [10]. By maximizing this value, one can determine that amount of interference that occurs between transmitters and receivers. This statistic is powerful for determining which user has the best connection to the UAV, thus allowing the UAV to focus its signal on that user. Scatterers and other user are key factors to the optimization of the SINR. Other users operating on the same frequency can cause path loss by creating interfering signals. In a selection combining algorithm, the SINR values between each receiver and transmitter are calculated, and the combination with the highest value is selected. Although this is an adequate first step towards interference mitigation, there are more powerful algorithms and methods that have been explored such as using multiple antennas, beamforming, and phase-shifting.

B. *Multiple Antenna Receivers*

Many factors contribute to interference between users and base stations. To combat this, researchers have developed techniques that use multiple antennas [11]. The additional use of antennas has seen growing impacts in the signal-to-interference-plus-noise (SINR) value. The use of multiple antennas as also been explored in multiple-ratio combining (MRC) and selection combining algorithms. The MRC model [12] tends to outperform the selection combining model because it has diversity gain. It combines multiple received signals, each with various levels of independent fading, which improves the overall reliability of the model. As long as the model has appropriate weights, it tends to outperform the selection combining model and produces the optimal SINR value [10]. Although the MRC model tends to be more reliable than the selection combining algorithm, the beamforming technique tends to be the best alternative to the MRC model [13].

C. *Beamforming*

UAVs tend to be limited in their ability to deliver high-speed communication, along with having limited energy for flights. To combat this problem, a technique known as beamforming has been developed. By using beamforming, the UAV is able to determine the direction of a strong transmission and direct its signal to the desired direction, thus maximizing the SINR [2]. This technique allows a drone to achieve wider ranges of transmission with lower interference. They have the ability to direct the signal into a set direction to enhance the signal to a user [1]. This helps decrease interference in terrestrial areas by providing a more direct route to a user, eliminating much of the unwanted path loss. Although the method of beamforming is fairly young, trends tell us that this method has potential to revolutionize the world of 5G communication [14]. Newer studies have experimented with UAV-controlled beamforming. Researchers found that the UAVs were not reliable in this setting due to their decisions not always being beneficial [15]. These researchers also found that the potential spatial interference reduction gains are insignificant when the UAV makes its own beamforming decisions. To improve the concept of beamforming, new research is being performed dealing with the concept of antenna phase-shifting to improve the efficiency of beamforming algorithms.

D. *Antenna Phase-Shifting*

Constant research is being done to improve upon the beamforming concept, with one of the more noteable methods being antenna phase-shifting. There are many methods and ideologies behind this concept, one of which involves creating dedicated cells for the UAVs and pointing the antennas towards the sky [16]. This method is projected to become more efficient as the number of UAVs being deployed increases. The concept of antenna phase-shifting is that the UAV is able to steer the signal in the direction of the desired user. Although this technique is similar to beamforming, antenna phase-shifting is simpler and more suitable for certain phased array arrangements.

IV. Conclusion

Wireless communication using UAVs has begun to revolutionize the way humans interact in the modern world. To successfully integrate the use of drones into daily lives, a significant topic of research has been interference mitigation. Every step towards limiting path loss and optimizing the signal-to-interference-plus-noise ratio (SINR) is progress towards implementing a cheaper and more adaptable source of communication. Further research will be performed to improve upon the world of 5G wireless communication using UAV technology.

References

[1] G. Sun et al., ”Collaborative Beamforming for UAV Networks Exploiting Swarm Intelligence,” in IEEE Wireless Communications, vol. 29, no. 4, pp. 10-17, August 2022, doi: 10.1109/MWC.001.2100677.

[2] W. Mei and R. Zhang, ”Aerial-Ground Interference Mitigation for Cellular-Connected UAV,” in IEEE Wireless Communications, vol. 28, no. 1, pp. 167-173, February 2021, doi: 10.1109/MWC.001.2000173.

[3] N. Rupasinghe, A. S. Ibrahim and I. Guvenc, ”Optimum Hovering Locations with Angular Domain User Separation for Cooperative UAV Networks,” 2016 IEEE Global Communications Conference (GLOBECOM), Washington, DC, USA, 2016, pp. 1-6, doi: 10.1109/GLOCOM.2016.7842113.

[4] A. Merwaday, A. Tuncer, A. Kumbhar and I. Guvenc, "Improved Throughput Coverage in Natural Disasters: Unmanned Aerial Base Stations for Public-Safety Communications," in IEEE Vehicular Technology Magazine, vol. 11, no. 4, pp. 53-60, Dec. 2016, doi: 10.1109/MVT.2016.2589970.

[5] Y. Zeng, R. Zhang and T. J. Lim, "Wireless communications with unmanned aerial vehicles: opportunities and challenges," in IEEE Communications Magazine, vol. 54, no. 5, pp. 36-42, May 2016, doi: 10.1109/MCOM.2016.7470933.

[6] M. Mozaffari, W. Saad, M. Bennis and M. Debbah, "Wireless Communication Using Unmanned Aerial Vehicles (UAVs): Optimal Transport Theory for Hover Time Optimization," in IEEE Transactions on Wireless Communications, vol. 16, no. 12, pp. 8052-8066, Dec. 2017, doi: 10.1109/TWC.2017.2756644.

[7] W. Khawaja, O. Ozdemir and I. Guvenc, "UAV Air-to-Ground Channel Characterization for mmWave Systems," 2017 IEEE 86th Vehicular Technology Conference (VTC-Fall), Toronto, ON, Canada, 2017, pp. 1-5, doi: 10.1109/VTCFall.2017.8288376.

[8] Z. Xiao et al., "A Survey on Millimeter-Wave Beamforming Enabled UAV Communications and Networking," in IEEE Communications Surveys Tutorials, vol. 24, no. 1, pp. 557-610, Firstquarter 2022, doi: 10.1109/COMST.2021.3124512.

[9] B. Van Der Bergh, A. Chiumento and S. Pollin, "LTE in the sky: trading off propagation benefits with interference costs for aerial nodes," in IEEE Communications Magazine, vol. 54, no. 5, pp. 44-50, May 2016, doi: 10.1109/MCOM.2016.7470934.

[10] L. Yue, "Analysis of generalized selection combining techniques," VTC2000-Spring. 2000 IEEE 51st Vehicular Technology Conference Proceedings (Cat. No.00CH37026), Tokyo, Japan, 2000, pp. 1191-1195 vol.2, doi: 10.1109/VETECS.2000.851313.

[11] Kapoor, R., Shukla, A., Goyal, V. (2022). Analysis of Multiple Antenna Techniques for Unmanned Aerial Vehicle (UAV) Communication. In: Senjyu, T., Mahalle, P., Perumal, T., Joshi, A. (eds) IOT with Smart Systems. Smart Innovation, Systems and Technologies, vol 251. Springer, Singapore. https://doi.org/10.1007/978-981-16-3945-6_34

[12] Q. T. Zhang, "Maximal-ratio combining over Nakagami fading channels with an arbitrary branch covariance matrix," in IEEE Transactions on Vehicular Technology, vol. 48, no. 4, pp. 1141-1150, July 1999, doi: 10.1109/25.775363.

[13] T. Izydorczyk, M. Bucur, F. M. L. Tavares, G. Berardinelli and P. Mogensen, "Experimental Evaluation of Multi-Antenna Receivers for UAV Communication in Live LTE Networks," 2018 IEEE Globecom Workshops (GC Wkshps), Abu Dhabi, United Arab Emirates, 2018, pp. 1-6, doi: 10.1109/GLOCOMW.2018.8644068.

[14] Jayaprakasam, S. & abdul rahim, Sharul & Leow, Chee Yen. (2017). Distributed and Collaborative Beamforming in Wireless Sensor Networks: Classifications, Trends and Research Directions. IEEE Communications Surveys & Tutorials. PP. 1-1. 10.1109/COMST.2017.2720690.

[15] T. Izydorczyk, G. Berardinelli, P. Mogensen, M. M. Ginard, J. Wigard and I. Z. Kovács, "Achieving High UAV Uplink Throughput by Using Beamforming on Board," in IEEE Access, vol. 8, pp. 82528-82538, 2020, doi: 10.1109/ACCESS.2020.2991658.

[16] V. Yajnanarayana, Y. . -P. Eric Wang, S. Gao, S. Muruganathan and X. Lin Ericsson, "Interference Mitigation Methods for Unmanned Aerial Vehicles Served by Cellular Networks," 2018 IEEE 5G World Forum (5GWF), Silicon Valley, CA, USA, 2018, pp. 118-122, doi: 10.1109/5GWF.2018.8517087.