Exploring Techniques to Mitigate Interference in Drone Communication Systems

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Abstract

Despite the apparent advantages and strong economic efforts for cellular-connected drones, several critical challenges must be tackled for their successful implementation. Like any radio communication system interference is considered as the biggest challenge as it significantly decreases the efficiency and reliability of the drone. The Monte-Carlo simulation (MCS) strategy is based on the principle of taking samples of random variables from a given distribution. These samples are then used to assess interference in terms of the interference received signal strength compared to the desired received signal strength commonly known as C/I or SNR. The results then are derived using SEAMCAT software as probability of interference where 1 means that this system is always interfered and 0 means it's never interfered. The study has been conducted for separation distances of 2,3,4, and 6 km between the victim receiver and the interfering transmitter where a lower interference probability was achieved as far as they were separated. A frequency allocation approach was also used during this study where we achieved lower interference probability when the systems were operating at a higher frequency.

Keywords: Drones, Victim link receiver, Interfering link transmitter, Probability of Interference, SEAMCAT, iRSS

1. Introduction

The telecommunication field is greatly benefiting from the promising potential of autonomous drone systems, which are also finding extensive use in various industrial applications. In [1] and [2] to address the problem of interference in drone communication, a study was conducted. They understand that interference can hinder communication and reduce the number of drones that can be used at once. By discovering different techniques, the aim is to create a more seamless and reliable communication experience for humans. In [1] it was discovered that successive interference cancellation and space division multiple access techniques can significantly enhance the maximum supported drone density without conceding reliability. In simpler terms, these techniques allow more drones to coexist in the same airspace without causing communication problems. This means that drone operators can fly closer together, ensuring they can capture footage or perform tasks without signal interference. [2] took a different approach by focusing on beamforming and coordinated multipoint (CoMP) techniques. By implementing these methods, they reduced interference by an impressive 13-15 dBm in line-of-sight conditions. In other words, they were able to significantly decrease the unwanted signals that drones receive, resulting in clearer and more reliable communication. This is particularly important for tasks that require real-time data transmission, such as drone inspections or surveillance operations. In [3] innovative solutions to mitigate interference in cellular-connected UAVs were proposed. They recognized that cellular networks often experience interference, which can affect the communication performance of drones. Mei's approach leverages the sensing capabilities of UAVs and inactive base stations to achieve more efficient and reliable operations. By using these resources effectively, they aim to optimize the communication performance of cellular-connected UAVs, ensuring a smoother experience for both drone operators and users. These studies contribute to making drone communication more human-friendly by addressing interference challenges. Through their innovative techniques and approaches, they aim to enhance the communication quality, reliability, and efficiency of drones, ultimately improving the overall user experience.

In recent studies, [4] and [5] have proposed innovative techniques that combine active noise control and spectral subtraction to improve the sound quality of videos recorded by drones. Their work focuses on making drone-captured videos more enjoyable for human viewers by reducing unwanted noise. Additionally, [5] has introduced a fascinating radar system called the Doppler signal-to-clutter ratio (DSCR) detector. This system effectively detects and extracts radar signals from small drones, resulting in a significant reduction in missed target rates. The goal is to enhance the accuracy and effectiveness of radar systems, making them more reliable in various applications. Moreover, [6] presented significant contributions by presenting a new method for estimating signal-to-noise ratio (SNR) in UAV OFDM systems. This method, known as non-data-aided (NDA) SNR estimation, outperforms other approaches, especially in scenarios where synchronization precision is low [7]. The focus here is to improve the performance of UAV OFDM systems, particularly in challenging environments, by providing more accurate SNR estimates. Together, these studies aim to humanize the technology used in drones by reducing noise, enhancing radar capabilities, and improving the overall performance of UAV OFDM systems. By doing so, they contribute to creating a more immersive and reliable experience for human users in various drone applications.

2. Methodology

2.1. *Monte Carlo Simulation*

The objective of this research is to explore and evaluate techniques for mitigating interference in a drone communication system using SEAMCAT software. The study aims to assess the effectiveness of various mitigation strategies in enhancing the performance and reliability of the drone communication system in the presence of interference. Thus, this study follows a simulation-based design utilizing SEAMCAT software. The Monte Carlo method, which serves as the foundation of SEAMCAT, is a statistical technique that sets itself apart from traditional analytical approaches that rely on solving differential equations to comprehend physical or mathematical systems. With Monte Carlo simulations, there is no need to explicitly formulate these equations; instead, we directly simulate the physical process. To employ the Monte Carlo method, we randomly select variables from known distributions. Prior to running the simulation, we must define all parameters of our radiocommunications system, such as antenna heights, powers, frequencies, and locations. For values that remain constant (like fixed frequencies or heights), they can be predetermined. We also obtain technical specifications from industry standards, such as those established by IEEE, 3GPP, and ETSI [8]. These distributions are used by SEAMCAT to produce random events. SEAMCAT keeps track of each event's interfering signal strength and computes desired signals in separate data arrays. Lastly, you can calculate the probability of interference by comparing each event's desired and unwanted signals at the victim link receiver to the applicable interference criterion, like C/I [8].

2.2. *Scenario*

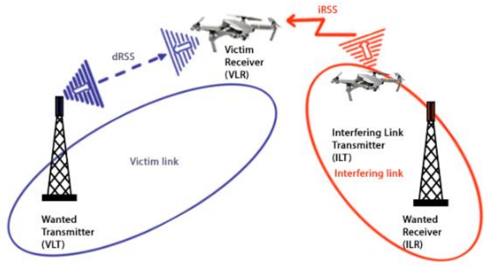

Fig. 1. System scenario.

As illustrated in Fig. 1 SEAMCAT simulates a scenario where a single victim link receiver (VLR) is connected to a victim link transmitter (VLT). This VLR operates in the presence of one or more interfering link transmitters (ILTs), which are paired with interfering link receivers (ILRs). The presence of the victim system, the interfering system, or both can lead to interference [8]. In order to replicate real-world interference situations, the interfering transmitters are strategically placed around the victim device. The user has the flexibility to define the distribution pattern, which can be either random or follow a specific relationship with respect to the victim's location. A crucial parameter in this context is the desired received signal strength (dRSS), which refers to the signal strength measured between the victim transmitter and receiver. The user has the ability to set the dRSS to a predetermined value. Additionally, the interfering received signal strength (iRSS) is measured between the interfering transmitter and the victim receiver. The iRSS serves as the primary metric for evaluating the extent of interference in the system [9].

The iRSS in our system is further divided into two main types known as $iRSS_{unwanted}$. Where the $iRSS_{unwanted}$ is the level of unwanted emissions (i.e. comprising of the out-of-band emissions and the spurious emissions of the ILT) lying within the VLR receiver bandwidth [8].

2.3. *Software Parameters*

The software parameters for SEAMCAT are detailed in this section, derived directly from ITU-R M.2233 to guarantee real-world relevance and adherence to operational standards [10].

Table 1. Victim & Interfering link parameters.

Parameter	Victim Link	Interfering Link
Operating Frequency (GHz)	5.03	5.06
Transmitting power (dBm)	40	40
Coverage radius (Km)	15	28
Propagation Model	ITU-R P.525 (Free Space)	ITU-R P.525 (Free Space)
Transmitter antenna Gain (dBi)	28	28
Receiving antenna Gain (dBi)	-10	-10
Reception Bandwidth (KHz)	37.5	37.5

According to [11] serious interference happens when the Carrier to Interference ratio (dRSS/iRSS or C/I) at the victim receiver is less than the allowable threshold. SEAMCAT produces random spatial and temporal distributions of VLT, ILT, VLR, and their parameters to find if the interference has occurred at the VLR or not. The user can adjust in the software interface the parameters of the VLT and ILT and the spatial position of VLT and ILT concerning each other. The parameters adjusted for the simulation of the victim link and Interfering link can be shown in Table 1.

When the carrier-to-interference ratio of the VLR falls below the minimum allowable protection ratio, interference occurs. The minimum protection ratio can vary depending on the modulation type, diverging from a standard value of 9 dB to higher levels [8]. Thus, interference is inevitable when the VLR's carrier-to-interference ratio fails to meet the minimum permitted protection ratio [11].

The Monte Carlo Simulation (MCS) process involves considering multiple independent events that take place at different locations and time frames. Each event is simulated by taking into account various random variables, such as the position of the interfering source relative to the victim. By incorporating these diverse scenarios, the received signal strengths (dRSS and iRSS) between the victim location receiver (VLR) and victim location transmitter (VLT), as well as between VLR and interfering location transmitter (ILT), can be computed. To obtain accurate results, a sufficient number of simulation attempts, typically around 20,000, are conducted. This ensures that the probability of interference can be reliably determined. Hence, it is recommended to use a significant number of simulation iterations to ensure consistent and dependable outcomes [11].

Four interference criteria are considered within SEAMCAT. C/I Carrier to interference ratio; C/(I+N) Carrier to interference plus noise ratio; (N+I)/N Noise plus Interference to noise ratio; I/N Interference to noise ratio. In our Scenario, we focus our study on the C/I and C/I+N, where we use the SEAMCAT built-in library to set the C/I threshold to 19dB and the C/I+N to 16dB.

3. Results and Discussion

Our methodology to mitigate interference is based on a parametric study to decrease the probability of interference the VLR undergoes to obtain more reliable communication throughout the victim link. This parametric study focuses on observing the probability of interference calculated by SEAMCAT under different distance separation scenarios between the VLR & ILT, as well as using different operating frequencies of VLR & ILT making sure they comply to the operating frequency band of drones specified by ITU. Our target here is to separate them as far as possible in order to get the best probability of interference possible complying with the interference criterion set previously, and without degrading the performance of our system

3.1. *Distance separation approach*

We use the separation distance between VLR & ILT as 2 km, and the victim link & interfering link both operate at the same frequency 5030 MHz, whereas all the rest of the parameters will be held constant throughout our observations.

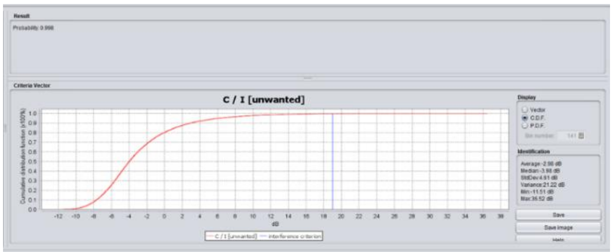

Fig. 2 iRSSunwanted at 2 Km separation distance

Fig. 2 is the result for $iRSS_{unwanted}$ at 2 Km separation distance, where we can divide the figure into 3 parts. First is the Criteria Vector where we see that the dRSS to iRSS ratio (dRss/iRSS) or C/I is plotted against the C.D.F. This plot illustrates the results obtained for dRSS/$iRSS_{unwanted}$. The second part is Identification where we focus on the Maximum power captured by the interferer in this case it's 36.52 dB. We focus on the Maximum power as it's the one above our criterion threshold. Finally, the third part, which is the result of the probability of interference gives us a 0.998 probability of interference which sets our target to decrease this number to mitigate system interference.

Table 1 Probability of interference of iRSSunwanted for distance separation between VLR & ILT.

Distance (Km)	**$iRSS_{unwanted}$**	
	Probability	**Max power (dB)**
2	0.998	36.52
3	0.995	34.96
4	0.991	40.07
6	0.98	50.89

Table 2 shows the results using the separation distance of 2,3,4,6 Km respectively, while the operating frequency is still held to 5030 MHz for both Links. From Table 2, we can observe that the probability of interference for the $iRSS_{unwanted}$ decreases as we increase the separation distance between the VLR & ILT, thus we can consider interference mitigation to our system. However, as soon as the separation distance is increased for more than 3 Km the Maximum interfering power is increased which is mainly because the ILT is randomly placed concerning the VLR while the VLT is held in a constant distance in respect to the VLR. This makes the VLR more vulnerable to greater interfering power.

3.2. *Frequency allocation approach*

For the first trial, we use the frequency for the victim link as 5045 MHz, and the interfering link as 5060 both complying with the ITU standard. When the VLR is placed 2 Km away from the ILT a better probability of interference of 0.997 is derived for both the $iRSS_{unwanted}$ that will be having the same values as depicted in Fig. 3.

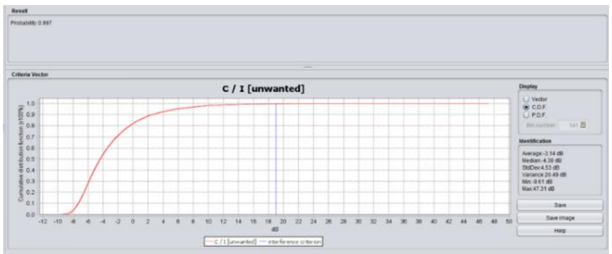

Fig.1 . iRSSunwanted when the Victim link operates at 5045 MHz & Interfering Link at 5060 MHz

Another crucial investigation we have come through is if both Links are to be operating at the same frequency, it's preferable to be a higher frequency. Fig. 3 illustrate that when both the Victim & interfering link are operating at 5060 MHz they achieve a lower interference probability of 0.987 for $iRSS_{unwanted}$ when the VLR is placed 2 Km away from the ILT. This is a better interference probability in comparison to when both the Victim Link & Interfering link were operating at 5030 MHz where they achieved a probability of 0.998.

4. Conclusion

In conclusion, the MCS method was used utilizing SEAMCAT software to assess the effect of distance separation & frequency allocation of the victim receiver in respect to the interfering transmitter on the probability of interference. The interference is divided into two types which are $iRSS_{unwanted}$. Both of the types achieved a significant lower probability of interference when the distance separation method was used. We reported a probability of interference of 0.998, 0.995, 0.991, and 0.98 for $iRSS_{unwanted}$ and 1, 0.999, 0.998, and 0.995 for $iRSS_{blocking}$ for the distance separation of 2,3,4, and 6 KM respectively. The separation distance of 3 km was prioritized as it captured the lowest interfering power. For the frequency allocation, the operation of systems on higher frequency presented lower interference probability of 0.987 for $iRSS_{unwanted}$ in comparison to operation on lower frequency when placed at the minimum separation distance.

References

1. Schalk, Lukas Marcel, Techniques for improving the cooperative traffic conflict detection among drones, 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring), IEEE, 2019.
2. Hee Fung Kim, and Mastaneh Mokayef, Interference Mitigation Techniques For The Operation Of Unmanned Aerial Vehicle (Uav), 2022 IEEE 5th International Symposium in Robotics and Manufacturing Automation (ROMA), IEEE, 2022.
3. Mei Weidong, and Rui Zhang, Aerial-ground interference mitigation for cellular-connected UAV, IEEE Wireless Communications 28.1 (2021): 167-173.
4. Ahn Hyohoon, et al., Hybrid Noise Reduction for Audio Captured by Drones, Proceedings of the 12th International Conference on Ubiquitous Information Management and Communication, 2018.
5. Kang Byungseok, Hyohoon Ahn, and Hyunseung Choo, A software platform for noise reduction in sound sensor equipped drones, IEEE Sensors Journal 19.21 (2019)
6. Gong Jiangkun, et al., Improved Radar Detection of Small Drones Using Doppler Signal-to-Clutter Ratio (DSCR) Detector, Drones 7.5 (2023): 316.
7. Li J., Liu M., Tang N., Shang B., Non Data-Aided SNR Estimation for UAV OFDM Systems, Algorithms 2020, 13, 22.
8. SEAMCAT Handbook Edition 2 (2016).
9. Mokayef Mastaneh, et al., Spectrum sharing model for coexistence between high altitude platform system and

fixed services at 5.8 GHz, International Journal of Multimedia and Ubiquitous Engineering 8.5 (2013): 265-275.

10. Examples of technical characteristics for unmanned aircraft control and non-payload communications links M Series Mobile, radiodetermination, amateur and related satellite services, (2011).
11. Girma, Solomon T., Dominic BO Konditi, and Ciira Maina, Frequency re-use distance calculation in cellular systems based on Monte-Carlo simulation, Heliyon 5.3 (2019).

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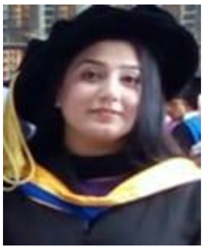

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