# Simulation-Based Enhancement of SNR in Drone Communication through Uniform Linear Array Configurations

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## Abstract

As drones navigate through shared airspace, they often encounter other drones, wireless devices, and communication systems. This coexistence creates potential sources of interference that can degrade the signal-to-noise ratio (SNR). To maintain reliable communication in drone systems, it is crucial to effectively manage and mitigate interference from other drones and wireless devices operating on the same frequency bands. By addressing these challenges, we can ensure a stable and dependable SNR for seamless communication among drones. This paper sheds light on the history of applications and challenges of utilizing flying base stations for wireless networks and analyzes different factors that affect signal-to-noise ratio (SNR) to enhance the performance of drone communication.

*Keywords*: SNR, UAV, drone, Matlab, IoT

## 1. Introduction

Unmanned aerial vehicles (UAVs) are set to play a crucial role in the next generation of wireless networks, offering a promising solution to meet the ever-increasing user demands. Their mobility, flexibility, improved line-of-sight capabilities, and ability to reach inaccessible areas make them ideal candidates to act as aerial base stations. Researchers are actively exploring various aspects of deploying, analyzing performance, managing resources, optimizing trajectories, and modeling channels in such networks. This survey article focuses on different applications and the algorithms involved in implementing aerial base stations, providing a comprehensive review of each research area. In summary, this article highlights the key applications, challenges, and technology employed in the design and analysis of UAVs as base stations.

In recent years, the widespread adoption of drones across various industries and applications has been remarkable. From capturing stunning aerial photographs to delivering packages, drones have become increasingly prevalent. One crucial factor that significantly influences the performance and efficiency of drone networks is the signal-to-noise ratio. The signal-to-noise ratio represents the ratio between the desired signal and unwanted noise in a communication system. A high signal-to-noise ratio is paramount for clear and reliable communication between drones and ground control stations, as well as for accurate data transmission [1]. However, achieving a high signal-to-noise ratio in drone networks presents several challenges [2]. The use of multiple drones operating in close proximity can result in interference and signal degradation, affecting the overall quality of communication. Moreover, the noise generated by the drones themselves, commonly referred to as ego-noise, can further impact the signal-to-noise ratio. These challenges necessitate careful consideration and innovative solutions to optimize the signal-to-noise ratio in drone networks, ensuring efficient and reliable communication between drones and ground control stations [3]. The interference experienced by each drone at a particular location can be measured by its signal-to-noise ratio (SNR). The SNR is influenced by multiple factors, including the transmission power levels, antenna properties, drone altitude, path loss, and the power spectral density of the surrounding noise. These variables collectively contribute to the observed interference levels and play a crucial role in determining the quality of communication in drone networks [4]. The altitude at which drones fly significantly impacts the signal-to-noise ratio in their networks. Higher altitudes result in larger distances between the transmitter and receiver, leading to a decrease in signal quality. Atmospheric attenuation further contributes to signal loss as altitude increases. Transmission power levels and antenna characteristics of drones also play a vital role in determining signal strength. Optimal power levels ensure overcoming noise and interference, while antenna properties affect signal coverage and directionality. Lastly, the noise power spectral density, originating from various sources, introduces background noise that affects the overall signal-to-noise ratio. Careful consideration of these factors is crucial for maintaining reliable communication in drone networks [5], [6], [7]. In [8], they delve into the realm of drone-assisted backscatter communication within an Internet of Things (IoT) sensor network. Their work focuses on developing a framework to evaluate the likelihood of ground-based sensor nodes being covered. Raja's study in 2021 explores how communication propagates between drones and base stations in indoor environments, taking into account factors like diffraction, frequency, and atmospheric attenuation [9]. While paper [10] proposes an innovative multi-UAV communication model that prioritizes security. This model employs a wireless mesh network and cryptographic techniques to ensure efficient and protected communication among multiple drones. The study underscores the significance of establishing reliable data communication security between drones and servers. Collectively, these papers offer valuable insights into coverage probability assessment, propagation mechanisms, multi-UAV coordination, and security measures within the realm of drone communication. To aid in understanding the communication requirements of UAVs, Table 1 concisely presents a summary of these requirements. This reference table offers a clear and accessible overview of the key aspects involved in UAV communication, making it easier for readers to grasp the necessary information.

Table 1: Essential Communication Requirements for UAV Systems

| | Data Type | Data Rate |
|---|---|---|
| DL | Synchronization (PSS/SSS) | N/A |
| | Radio control (PDCCH) | |
| | Command and control ( C&C) | 60-100 kbps |
| UL | Command and Control (C &C) | 60-100 kbps |
| | Application data | Up to 50 Mbps |

A Comparative Study of the distinctive features of drone types are presented in [9], [10], [11] and the summary of these results is tabulated in Table 2.

Table 2: Distinctive Features of Drone Types [11], [12]

| | Micro (weight6100g) | Very Small (100g<weight<2kg ) | Small (2kg6weight<25kg) | Medium (25kg6weight6150kg) | Large (weight>150kg) |
|---|---|---|---|---|---|
| Model | Kogan nano drone | Parrot Disco | DJI Spreading Wings S900 | Scout B-330 UAV helicopter | Predator B |
| Illustration | A<br>16g N/A<br>Multi-rotor | B<br>750g<br>N/A<br>Fixed-wing | C<br>3.3kg<br>4.9 kg<br>Multi-rotor | D<br>90kg<br>50kg<br>Multi-rotor | E<br>2223kg<br>1700kg<br>1700kg<br>Multi-rotor |
| Weight | 16g | 750g | 3.3kg | 90kg | 2223gg |
| Payload | N/A | N/A | 4.9kg | 50kg | 1700kg |
| Flying mechanism | Multi-rotor | Fixed-wing | Multi-rotor | Multi-rotor | Multi-rotor |
| Range | 50-80 m | 2km | N/A | N/A | 1852km |
| Altitude | N/A | N/A | N/A | 3km | 15km |
| Flight time | 6-8 min | 45min | 18min | 180min | 1800min |
| Speed | N/A | 80 km/h | 57.6 km/h | 100km/h (horizontal) | 482km/h |
| Power supply | 3.7V/160mAh Li-battery | 2700mAh/25A 3-cell<br>LiPo Battery | LiPo Battery (6S, 10000mAh_15000mAh, 15C(Min)) | Gasoline | 950-shaft-horsepower Turboprop Engine |

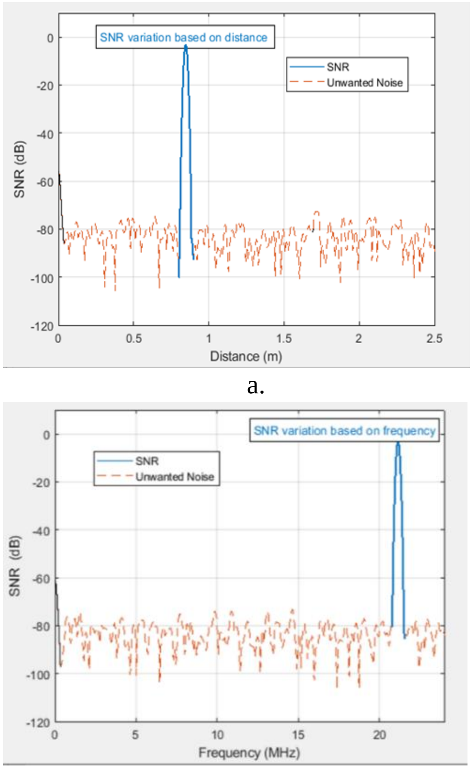
## 2. Methodology

### 2.1. Performance evaluation Through SNR strength

Unmanned aerial vehicles (UAVs) have gained significant popularity, due to their autonomous features, versatility, and wide range of applications. In this section, we will delve into a detailed evaluation of drone performance. Our main focus will revolve around analyzing a key metric of the SNR. This metric will be used to thoroughly assess and scrutinize the effectiveness of drone operations, providing valuable insights into their overall efficacy. SNR is commonly expressed in decibels and represents the ratio of signal power to noise power. An SNR greater than 1:1 (greater than 0 dB) indicates that the signal is stronger than the noise. When information is transmitted wirelessly from one point to another, it is referred to as a data link. In the context of unmanned aviation, this wireless transmission is known as a radio link or radio modem. The data link enables the exchange of information between the aircraft's autopilot and the Ground Control Station (GCS). This communication involves two distinct links: the uplink, which transmits information from the GCS to the aircraft, and the downlink, which transmits information from the aircraft to the GCS. Eq. (1) is used to calculate the SNR level.

$$SNR\ (dB) = \ P_{signal}\ (dB) - \ P_{noise}\ (dB) \quad (1)$$

Where P is the power. The power levels can be expressed in decibels per dBm. The range at which a drone can fly in relation to a base station is determined by the minimum SNR required for the specific application. It is important to establish the maximum distance that can be achieved while maintaining the desired SNR. During flight, the SNR changes as the drone moves through different distances, adapting to meet the target SNR. To illustrate this relationship, Fig. 1 depicts a simulation graph created using MATLAB, showing how the SNR is influenced by the distance traveled by the drone.



a.

b.

Fig. 1 SNR as a function of (a) distance traveled by drone, and (b) frequency of operation [13]

### 2.2. *SNR enhancement methods*

The analysis presented in Fig. 1 provides valuable insights into the significance of the signal-to-noise ratio (SNR) in determining the quality of output. The observed threshold value for SNR is -10 dB; however, to achieve optimal output quality, it is recommended to have an SNR higher than -20 dB. The graph illustrates a gradual decline in signal quality as the range increases, with the highest signal quality observed in close proximity to the transmitter. Considering the fixed parameters of a frequency threshold of 2.4 GHz, a power threshold of 1W, and a specific distance, it becomes evident that a stronger signal is required at a distance of 1m and a frequency of 10 MHz, with a transmit power of 1W [11]. This is due to the reduced interference from various sources such as remote controls, phones, Bluetooth devices, plants, and buildings, which tend to degrade the signal quality. As the distance between the transmitter and receiver increases, the SNR decreases, indicating weaker signal quality at longer ranges.

## 3. SNR enhancement by Array Gain for Line-of-Sight Propagation

SNR enhancement by array gain is a technique used to improve the quality and reliability of wireless communication in line-of sight propagation scenarios. Modern wireless communication systems often implement large-scale antenna arrays to take advantage of the benefits offered by array gain [14]. To improve the SNR level and consequently wireless communication, we proposed the use of an array antenna instead of the single antenna into the drone side [15], [16]. The SNR is calculated and compared for both SISO and SIMO cases using Eq. (2) and Eq. (3) respectively.

$$SNR_{siso} = \frac{P_t G_t G_r \lambda^2}{4\pi d^2 N_0} \quad (2)$$

Where $P_t, G_t, G_r,$ and $\lambda$ are transmitted power, Transmitted gain, Received gain and wavelength of transmitted signal respectively. The $d$ and $N_0$ also stands for distance between transmitter-receiver, and the noise power.

$$SNR_{siso} = \frac{P_t G_t \sum G_{ri} \lambda^2}{4\pi d^2 N_0} \quad (3)$$

Where $G_{ri}$ is the gain of the i-th receiving antenna.

The result of these calculations has been presented in a comparison way showing the energy per bit to noise power spectral density ratio. This technique is commonly used as a metric to quantify the quality of a communication system in terms of the received signal power and the noise power affecting the transmission.

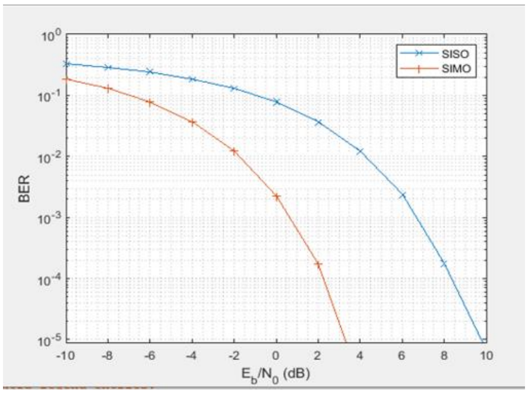


Fig. 2 Energy per Bit to Noise Power Spectral Density Ratio (E/N) Comparison for SISO and SIMO Systems

Due to the LOS communications, the transmitter and receiver are in direct communication. For the ease of calculation, a four-element Uniform Linear Array (ULA) with half-wavelength spacing, is considered in our simulations. The SISO and SIMO channel BER and the energy per bit to noise power spectral density ratio is depicted in Fig. 2. In a SIMO system, the BER curve demonstrates a notable improvement of 6 dB when a receive array is utilized. This gain is primarily attributed to the coherent nature of the received signals that interact with the components of the receive array. As a result, the receive array can be strategically oriented towards the transmitter, leading to an enhanced Signal-to-Noise Ratio (SNR). This phenomenon indicates that the receiver has knowledge of the incoming signal path, allowing for improved performance in terms of signal quality and error rate. The observed gain can be explained by the fact that the received signals around the receive array components exhibit coherence. This coherence arises due to the spatial diversity provided by multiple antennas in the receive array. Each antenna captures multiple instances of the transmitted signal, with slight variations in phase and amplitude. When these signals are combined, they undergo constructive interference, leading to an increase in the overall received signal power. This phenomenon highlights the advantage of utilizing a receive array with multiple antennas, as it enables the system to effectively capture and utilize the coherent signals, resulting in improved signal strength.

## 4. Conclusion

In summary, this research paper emphasizes the significant role of Unmanned Aerial Vehicles (UAVs) in wireless networks, offering a wide range of applications such as aerial base stations, wireless network user services, and mobile relays in flying ad-hoc networks. Deploying UAV base stations can greatly enhance wireless network coverage and power, enabling communication in various scenarios, including those where the dissemination of public safety information is critical. Furthermore, UAVs show promise in supporting secure and energy-efficient millimeter-wave communications and Internet of Things (IoT) communications. When equipped with cellular links, drones require secure and low-latency communication with ground base stations. The coherent nature of received signals through the Single-Input Multiple-Output (SIMO) receive array presents an opportunity to direct the array towards the transmitter, thereby increasing the Signal-to-Noise Ratio (SNR). Analysis of the Bit Error Rate (BER) curve reveals a gain of 6 dB achieved through the utilization of the receive array. This gain indicates that the receiver has knowledge of the incoming signal path. These findings highlight the advantages of incorporating UAVs into wireless networks, showcasing their potential to enhance coverage, power, and communication capabilities. The ability to steer the receive array towards the transmitter, coupled with the coherent nature of received signals, contributes to improved SNR and overall system performance. Future research can focus on optimizing UAV deployments, refining beamforming techniques, and exploring additional applications where UAVs can be effectively utilized in wireless networks. By harnessing the capabilities of UAVs in these contexts, advancements can be made towards more secure, reliable, and efficient wireless communication systems.

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