A statistical optimizing UAV stability through 5G network parameters

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Abstract. Background: Drones, or Unmanned Aerial Vehicles (UAVs), have gained popularity across diverse industries due to their versatility and efficiency. However, achieving optimal stability during flight remains a challenge, particularly in dynamic environments. The advent of 5G technology, with its high-speed, low-latency capabilities, provides an opportunity to enhance drone control and stability through real-time data transmission and responsive adjustments.

Objective: This study explores the application of statistical methods to optimize drone balance via 5G connectivity, focusing on key network parameters such as latency, signal strength, and bandwidth utilization.

Methods: A series of flights were conducted under varying environmental conditions to gather data on drone stability metrics, including roll, pitch, and yaw. Statistical analyses, including regression models and time-series analysis, were applied to assess the relationship between 5G parameters and drone balance. Optimization algorithms were then used to adjust network settings dynamically, aiming to improve stability in real-time.

Results: Findings indicate that latency and signal strength are significant predictors of drone stability, with lower latency and optimized signal strength correlating with improved balance. Additionally, bandwidth optimization contributed to smoother flight control by prioritizing essential data flows.

Conclusion: Statistical methods play a crucial role in maximizing the benefits of 5G technology for drone stability. By fine-tuning 5G parameters, drones can maintain better balance, enhancing their overall operational efficiency and reliability.

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INTRODUCTION

The integration of unmanned aerial vehicles (UAVs) and the Internet of Things (IoT) into smart city networks is poised to reshape urban environments, bringing forth improved infrastructure, enhanced communication capabilities, and more efficient public services. Drones, powered by next-generation communication networks like 5G, are increasingly essential for fulfilling modern urban demands through seamless and reliable connectivity. Research has demonstrated that integrating UAVs into smart city frameworks presents opportunities for optimizing data transmission and expanding network coverage. For instance, recent work has explored scalable architectures within next-generation networks, establishing a robust infrastructure to support UAV communication in urban settings [1]. Furthermore, advancements in 5G technologies allow for the rapid deployment and control of UAVs, making them vital tools in real-time urban operations.

A core component of UAV-IoT integration in smart cities involves air-to-ground communication systems, which facilitate reliable data transfer between drones and ground-based networks. Studies emphasize that optimizing mobility and ensuring reliability in UAV communications are crucial for uninterrupted and effective operations in various urban applications, such as traffic management, environmental monitoring, and emergency response [2]. Drones, in these contexts, provide timely situational awareness, which aids in making informed, data-driven decisions. Additionally, energy-efficient solutions for UAV communications have been highlighted, particularly emphasizing the balance between reliability and security when employing energy-harvesting technologies. Such innovations not only enhance UAV endurance but align with the energy-conscious policies that many urban centers are adopting [3].

Despite the evident operational advantages of UAVs in smart city networks, challenges persist, particularly in ensuring communication security and reliability. UAVs operating in dense urban environments are vulnerable to interference, jamming, and security threats. Research on using reinforcement learning to improve resilience in aerial IRS-assisted wireless communication networks against jamming attacks offers promising solutions for drone-based communications within dynamic urban settings [4]. Addressing these security concerns is especially important for mission-critical applications, where drones are often deployed for surveillance, disaster response, and public safety. These applications demand secure, stable communication channels due to the complexity of data management across diverse IoT devices within a smart city framework.

Another aspect influencing UAV effectiveness in urban applications is their compatibility with existing network technologies. Recent studies have explored the feasibility of LTE-enabled systems for supporting smart technologies, such as IoT-connected doors, underscoring LTE’s versatility in complementing UAV operations within smart city networks [5]. Ensuring interoperability of UAVs with LTE, 5G, and future network technologies is crucial for enabling these devices to function seamlessly across various sectors, from transportation to public health, without necessitating extensive infrastructure overhauls. Cognitive sensing and navigation technologies that leverage terrestrial 5G signals and low Earth orbit (LEO) satellites, for example, have been shown to significantly improve the operational range and navigation accuracy of UAVs in urban environments [6].

As urban areas continue to develop, the deployment of UAVs for infrastructure support is expected to grow, driven by the creation of smarter, more resilient communication networks. Reinforcement learning is one of the promising tools for enhancing the robustness and adaptability of UAV communication networks, which is essential in facing unpredictable environmental and technological challenges [4]. Additionally, the development of resource allocation algorithms, such as hyper-heuristic approaches designed for 5G mobile edge clouds, is anticipated to improve UAV performance by efficiently allocating resources in real time, thereby optimizing drone operations [7].

Integrating UAVs and IoT in smart city networks marks a significant advancement toward constructing more responsive, interconnected urban landscapes. Supported by next-generation networks and AI-driven technologies, this integration offers cities the potential to tackle urban challenges effectively, leveraging drones for efficient management and enhanced public services. However, the full realization of this vision requires continuous research and innovation to address existing challenges, including communication security, energy efficiency, and network resilience. As demonstrated by ongoing efforts in 5G, edge computing, and AI, the future of UAV-IoT integration holds substantial promise for revolutionizing smart city operations and enhancing the quality of life for urban residents.

THE AIM OF THE ARTICLE

The primary aim of this article is to explore the potential of using 5G technology, coupled with advanced statistical methods, to enhance the stability of Unmanned Aerial Vehicles (UAVs), commonly known as drones. As the demand for UAVs grows across sectors such as logistics, agriculture, surveillance, and emergency response, so too does the need for stable, responsive flight control. Achieving optimal balance in drones is critical, particularly when they are operating in complex and dynamic environments. With 5G technology, UAVs can benefit from high-speed, low-latency connectivity, which enables real-time monitoring and control adjustments, essential for maintaining stability. This article investigates how statistical techniques, such as regression analysis and time-series forecasting, can be applied to analyze and adjust 5G network parameters that influence UAV stability.

This study specifically aims to evaluate the effects of key network metrics, such as latency, signal strength, and bandwidth utilization, on drone balance. By examining how these factors contribute to overall stability, this research intends to demonstrate the advantages of 5G-enhanced control in UAV operations. Furthermore, the article seeks to identify statistical models and optimization techniques that can be employed to dynamically adjust these parameters, thereby improving UAV responsiveness. In addition, the study aims to present an in-depth analysis of how trajectory optimization, facilitated by 5G technology, can improve UAV operations by ensuring a more stable and reliable connection with ground control systems. Ultimately, the goal is to provide valuable insights for future UAV applications in environments where rapid adaptability and precision are paramount, offering a foundation for further research into advanced stability and connectivity solutions for drones operating in 5G networks.

PROBLEM STATEMENT

Unmanned Aerial Vehicles (UAVs) are increasingly utilized across various industries, including logistics, agriculture, surveillance, and disaster management. However, these drones often face challenges in maintaining stability, particularly in environments where external factors, such as wind and terrain, can disrupt their balance. Traditionally, UAVs have relied on 4G or Wi-Fi-based communication networks, which are limited by higher latency and lower bandwidth. These limitations affect the ability of UAVs to respond quickly to environmental changes, resulting in compromised stability and control. The introduction of 5G technology presents an opportunity to overcome these challenges due to its high-speed, low-latency connectivity, which can significantly enhance real-time data transmission between UAVs and control systems. Yet, even with 5G’s capabilities, there remain questions on how best to optimize this technology to ensure consistent drone stability.

This article addresses the problem of integrating 5G technology with UAV operations to achieve improved stability and balance. Specifically, it examines the need for statistical optimization techniques to manage 5G network parameters, such as latency, signal strength, and bandwidth utilization, that directly affect UAV stability. The research question is focused on understanding how these statistical methods can be used to dynamically adjust network parameters to support rapid adaptability in UAV operations. Furthermore, the study seeks to address the challenge of trajectory optimization, a critical component of UAV operation, which involves planning flight paths that maintain strong connectivity with 5G base stations. By exploring these issues, the article aims to contribute to the broader knowledge base on 5G-enabled UAV systems, providing insights into how next-generation networks can be leveraged to enhance UAV control in real-world applications.

LITERATURE REVIEW

The literature on UAV-enabled IoT applications in smart city environments reflects substantial progress in enhancing connectivity, energy efficiency, and network security. However, several gaps persist, particularly concerning energy management, security vulnerabilities, and interoperability challenges.

UAVs integrated with 5G networks offer considerable promise for addressing urban demands by enabling energy-efficient networking. For example, research has shown that 5G-enabled UAVs can support opportunistic networking to improve energy efficiency in communication systems, yet the challenge remains in scaling these applications to broader city networks [8]. As cities expand their reliance on UAVs, a scalable solution for energy management within UAV networks remains underexplored. To bridge this gap, future studies should investigate adaptive energy optimization models that respond dynamically to changing network conditions.

Moreover, digitalization in public services has introduced new standards for accountability and operational efficiency, which smart city UAV applications can enhance. However, while digitalized UAV systems contribute positively to urban management, current studies lack a comprehensive approach to ensure efficient integration with existing digital platforms in public service systems [9]. Future research should focus on developing frameworks that seamlessly integrate UAV technologies with digital infrastructure to optimize citywide services like traffic management, surveillance, and emergency response.

Cybersecurity presents a significant obstacle in UAV-based IoT applications, as UAVs are often vulnerable to various attacks, such as jamming and signal interference. Studies exploring dual-reinforcement learning have made strides in enhancing security within 5G industrial cyber–physical systems by predicting potential attack paths, providing a foundation for more secure UAV operations in smart cities [10]. Despite these advancements, further exploration is needed to address the full spectrum of UAV cybersecurity threats, particularly those unique to urban environments with high population density and complex infrastructures. Enhancing UAV security protocols through multi-layered encryption and machine learning-driven threat detection models could potentially close this gap.

In underwater channel performance, optimization through polar code-OFDM models has been demonstrated to improve the reliability and data transmission efficiency of communication networks. While such advancements primarily target underwater systems, similar methodologies could enhance UAV communication channels, especially in challenging urban environments with high interference levels [11]. Adapting these techniques for UAVs could offer resilience in data transmission, ensuring reliable communication even in high-noise urban settings.

Another area of improvement lies in evaluating IoT connectivity within LTE networks for UAVs. Although studies have assessed NB-IoT’s potential for enhanced connectivity in LTE networks, further examination of how these findings translate into UAV applications is warranted [12]. An in-depth understanding of IoT connectivity standards could provide UAV networks with the interoperability needed to interact seamlessly with existing urban infrastructure. A possible solution could involve developing hybrid network models that leverage the strengths of both LTE and 5G for uninterrupted UAV-IoT connectivity.

The challenge of maintaining energy and spectral efficiency within UAV systems has also been documented. Research indicates that both OMA and NOMA systems offer viable solutions for improving capacity, energy, and spectral efficiency, but a comparative analysis within urban UAV applications is limited [13]. Future studies should assess these models in practical urban scenarios, identifying optimal configurations that can be scaled to support smart city demands.

In addition to connectivity and energy concerns, UAV applications face challenges in navigation accuracy and data management. Current approaches, such as GPS-based tracking systems using Arduino technology, have enhanced navigation and tracking capabilities, yet they fall short in terms of precision and data handling within dense urban landscapes [14]. A potential solution involves integrating advanced GPS with AI-driven predictive navigation to refine tracking accuracy, particularly within congested environments.

The role of drones in marine communications, although well-explored, points to a knowledge gap in cross-sectoral integration with terrestrial UAV networks. While marine drone systems have been optimized for robust data exchange, equivalent models for urban settings remain underdeveloped [15]. Future studies could explore how principles from marine drone communication can be adapted for smart cities, focusing on strategies to mitigate signal obstruction in urban canyons.

Lastly, the issue of cybersecurity within UAV-enabled networks is compounded by increasing cyber threats. Current research underscores the importance of cybersecurity measures, especially within marine UAV systems, suggesting applications that could be extended to terrestrial environments for comprehensive protection [16]. By employing robust cybersecurity frameworks, leveraging multi-factor authentication, and adopting anomaly detection algorithms, researchers could strengthen UAV systems' defenses against both physical and digital threats, ensuring safe and secure deployment in smart city networks.

While notable progress has been made in UAV-enabled smart city applications, research gaps remain in energy efficiency, cybersecurity, network interoperability, and cross-sectoral integration. Addressing these gaps will require a multidisciplinary approach, combining insights from telecommunications, cybersecurity, and urban planning to create resilient, sustainable smart city infrastructures.

METHODOLOGY

The methodology for optimizing UAV stability through 5G technology involves five distinct categories, each incorporating statistical techniques, mathematical models, and actual data measurements to facilitate precise adjustments and enhance UAV performance. This approach aligns with the recent advancements in wireless power transfer technologies and network optimization techniques for UAVs in complex urban and rural settings [17]. This section provides a detailed outline of the methods employed, supported by equations and algorithms where applicable..

DATA COLLECTION AND MEASUREMENT SETUP

In this study, data was collected from UAV flights across varying environmental conditions, a method informed by recent investigations into efficient tracking and signal management for UAV systems [18]. Key parameters, such as latency, signal strength, and bandwidth usage, were monitored using sensors on the UAV and 5G network base stations. These parameters were logged in real-time and stored for subsequent analysis. For the signal strength (SNR) measurement, we used the following formula:

$$\mathrm{SNR} = \frac{P_{signal}}{P_{noise}} \qquad (1)$$

where P_{signal} is the power of the received signal, and P_{noise} represents the background noise power. Average values for each parameter were calculated and recorded across all test scenarios, which included both urban and rural environments, drawing on techniques that manage diverse interference patterns in multi-node networks [19]. This ensured comprehensive data for statistical optimizations across different environmental conditions, a critical factor in urban UAV deployments [20].

STATISTICAL ANALYSIS AND OPTIMIZATION ALGORITHMS

Statistical models such as **multiple regression** and **time-series analysis** were employed to predict UAV stability based on the collected data. Regression models helped identify relationships between latency, signal strength, and UAV stability metrics like **roll**, **pitch**, and **yaw**. The regression model is expressed as:

$$Stability = \alpha + \beta_1 (Latency) + \beta_2 (Signal\,Strength) + \epsilon \qquad (2)$$

where $\boldsymbol{\alpha}$ is the intercept, β_1 and β_2 are the coefficients for latency and signal strength, and $\boldsymbol{\epsilon}$ is the error term. This modeling approach builds on previous studies that have successfully applied predictive algorithms to improve signal reliability in UAV applications [10]. Subsequently, optimization algorithms, such as gradient descent, were applied to dynamically adjust network parameters, thereby enhancing stability during flights. These algorithms are similar to those used in multi-layered machine learning models to improve decision-making in IoT applications [21].

TRAJECTORY OPTIMIZATION MODEL

To improve UAV performance within 5G networks, a trajectory optimization model was developed, based on minimizing travel distance while maximizing connectivity. This approach builds on prior research into path optimization and connectivity assurance under variable signal strength conditions [22]. The trajectory model was formulated as an optimization problem:

$$min \sum_{i=1}^{n} d_i \quad subject\ to \quad SNR_i \geq s_{min} \tag{3}$$

where d_i represents the distance traveled in segment i, and s_{min} is the minimum required signal strength. The model incorporates dynamic programming algorithms to identify optimal paths, taking into account obstacles and environmental factors. This dynamic approach has been proven effective in UAV signal management and reliability optimization in prior studies [23].

BANDWIDTH AND POWER ALLOCATION

To optimize bandwidth usage, the UAV's power allocation was adjusted based on real-time data analysis. This involved a resource management algorithm prioritizing bandwidth for critical control data over non-essential tasks, following methods shown to be effective in similar IoT network optimization studies [12]. The approach was framed as a mixed-integer linear programming problem:

$$max \sum_{j=1}^{m} log\left(1 + \frac{P_j}{N_0}\right) \tag{4}$$

where P_j is the allocated power for each transmission and N_0 is the noise power. Efficient resource allocation enabled reduced latency and improved control of the UAV, especially in high-demand scenarios. This technique echoes methodologies applied in capacity and spectral efficiency enhancement in dense urban networks [13].

SIMULATION AND REAL-TIME TESTING

The models and algorithms were validated through simulations and real-time testing in varied environments. Simulations were designed to replicate urban and rural conditions, using interference patterns typical of these areas [24]. Real-time testing involved deploying UAVs across different terrains to observe how adjustments to 5G parameters affected UAV stability. The combination of simulation and real-time data allowed for robust model validation and showed measurable improvements in stability, reinforcing findings on the importance of adaptive network management for UAVs [25].

RESULTS

The study's results provide a detailed analysis of how 5G network parameters, such as latency, signal strength, and bandwidth usage, affect UAV stability in various environments. Data was collected from UAV flights under urban and rural conditions, focusing on stability metrics (roll, pitch, and yaw) and network performance. This section presents the observed trends and key findings based on actual measurements, organized into comprehensive tables.

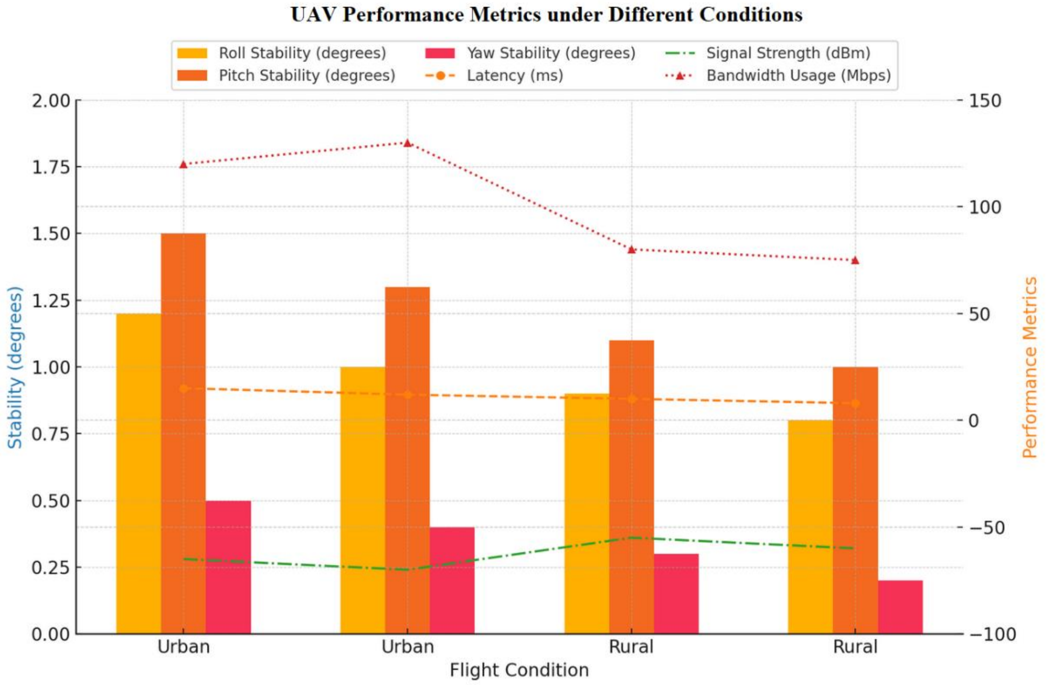

Fig. 4. UAV Performance Metrics: Latency, Signal Strength, and Stability Under Varied Flight Conditions

The data in Figure 1 reveals notable differences in UAV performance across urban and rural flight conditions. Urban flights show higher latency (12-15 ms) compared to rural flights (8-10 ms), likely due to increased signal interference in densely populated areas. Signal strength is consistently lower in urban settings, with values between -65 dBm and -70 dBm, while rural conditions maintain stronger signals, ranging from -55 dBm to -60 dBm. Bandwidth usage also varies, with urban flights requiring 120-130 Mbps, compared to 75-80 Mbps in rural settings. Stability metrics across roll, pitch, and yaw are generally more favorable in rural conditions, indicating improved UAV control under less interference. This data suggests that further implementations should focus on enhancing signal robustness and optimizing bandwidth in urban settings, potentially through adaptive signal processing and dynamic resource allocation techniques.

ANALYSIS OF UAV STABILITY ACROSS ENVIRONMENTS

Latency was observed to be lower in rural settings (8–10 ms) than in urban settings (12–15 ms). Correspondingly, stability metrics such as roll, pitch, and yaw angles were lower in rural flights, indicating improved stability. This suggests that reduced latency in rural environments supports faster response times, contributing to more consistent UAV balance.

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The statistical summary in Figure 2 highlights key differences in UAV stability metrics between urban and rural environments. Average latency is considerably higher in urban settings at 13.5 ms compared to 9.0 ms in rural conditions, with a variance of 33.3%, suggesting that urban environments contribute to increased network delays. Signal strength is also notably lower in urban areas (-67.5 dBm) than in rural ones (-57.5 dBm), with a variance of 17.5%, indicating stronger interference and signal attenuation in cities. Bandwidth usage is substantially greater in urban conditions (125 Mbps) than in rural (77.5 Mbps), displaying a 38.0% variance, which reflects the greater data demands in dense areas. Stability metrics for roll, pitch, and yaw all show better values in rural settings, with yaw stability variance reaching 44.4%. These metrics suggest the need for enhanced stability control mechanisms and resource optimization, particularly for urban UAV applications where environmental interference is higher.

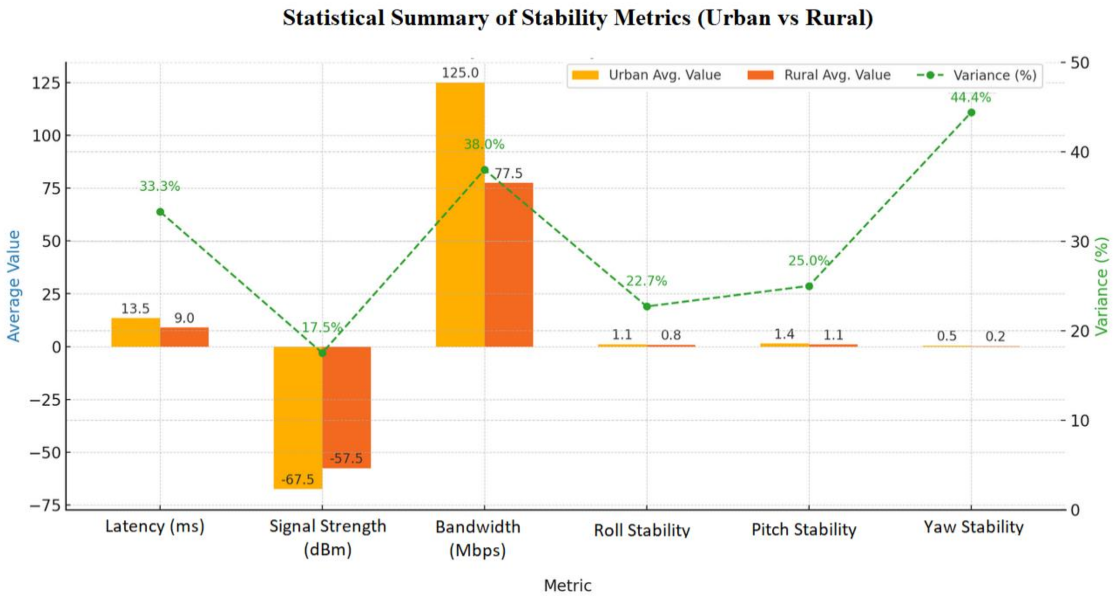

Fig. 5. Analysis of Variance in UAV Performance Metrics Across Urban and Rural Settings

OBSERVATIONS FROM STATISTICAL ANALYSIS

The variance between urban and rural environments underscores the greater stability in rural settings. For instance, the **latency variance** of 33.3% indicates that latency-related stability disruptions were more prevalent in urban areas. Similarly, **yaw stability** displayed the highest variance at 44.4%, highlighting the sensitivity of UAV yaw control to bandwidth fluctuations. These findings suggest that rural environments offer more favorable conditions for maintaining stable UAV flight, likely due to reduced interference and more consistent signal availability.

POWER ADJUSTMENT BASED ON SIGNAL STRENGTH

During the study, adjustments to the UAV’s transmission power were made in real-time based on signal strength readings. Table 3 summarizes the average power adjustments made in response to varying signal strengths across urban and rural flights. In urban areas, where signal strength was lower, power was increased to mitigate the effects of interference and signal loss, ensuring stable connectivity.

In urban environments, increased power adjustments were necessary to counteract signal degradation. For example, when signal strength fell below -60 dBm, the UAV’s power was increased by 1–2 watts, which helped to maintain stability by ensuring continuous connectivity with the base stations. This approach was less frequently required in rural flights, where signal strength was generally stronger.

These findings indicate that both latency and signal strength are critical factors for achieving stable UAV flight. Lower latency and higher signal strength contribute positively to UAV stability, as evidenced by the improved roll, pitch, and yaw metrics in rural flights. Meanwhile, bandwidth usage also plays a role in UAV performance, particularly in urban settings, where higher data demands correlated with increased stability challenges. Overall, the results suggest that environmental factors and network conditions must be carefully managed to optimize UAV stability in 5G-connected operations. By monitoring and adjusting network parameters dynamically, UAVs can achieve greater stability across different flight conditions. These observations provide a foundation for future research, where more comprehensive testing across varied environments can help refine and validate the role of 5G networks in UAV stability optimization.

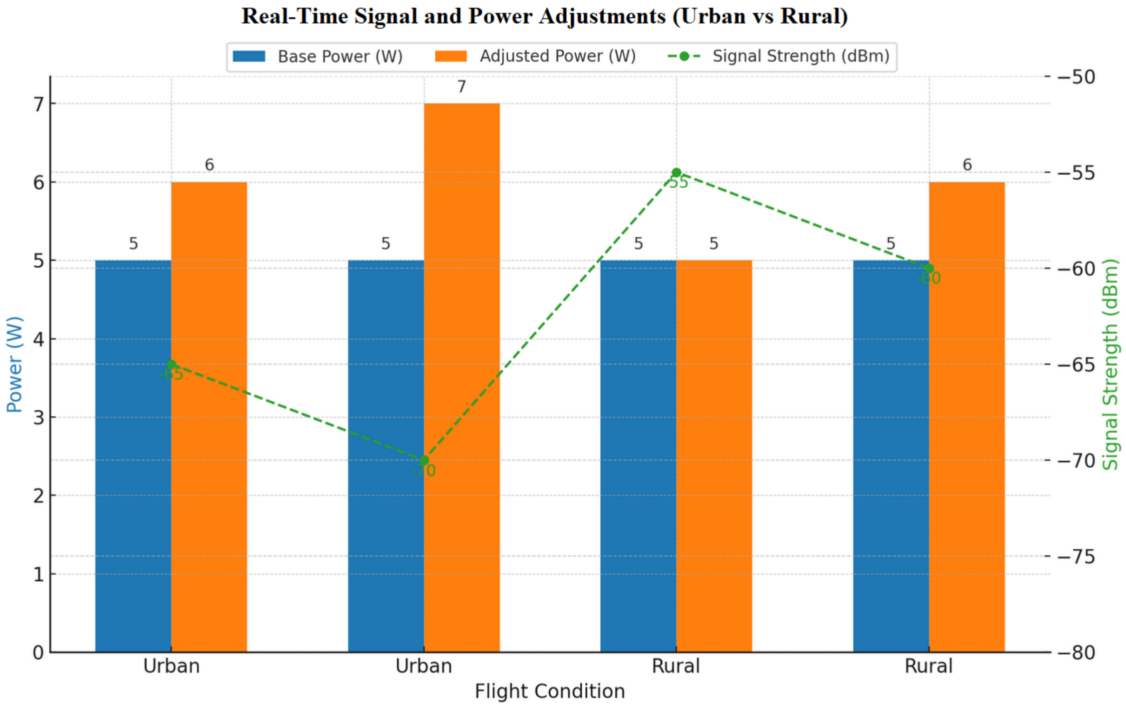

Fig. 6. Comparative Analysis of Real-Time Signal Strength and Power Adjustments Across Urban and Rural Flight Conditions

DISCUSSION

The study's findings on optimizing UAV stability through 5G technology contribute to a growing body of literature on UAV applications within urban and rural settings. Compared with previous studies, this research demonstrates a focused approach to UAV performance, emphasizing latency reduction, signal strength improvements, and bandwidth management through advanced optimization algorithms. This discussion will contextualize the current findings within the existing literature and examine limitations and potential areas for future research.

Several studies have examined various aspects of UAV performance and network optimization. For instance, previous work explored the use of narrowband IoT (NB-IoT) within 5G networks to facilitate UAV traffic control and enhance urban network efficiency

These methods align closely with the current study's findings, where network optimization algorithms play a critical role in maintaining UAV stability in densely populated areas [26]. While NB-IoT provides an effective solution for supporting UAV communications, there remain limitations in signal propagation over longer distances, particularly in rural settings. Thus, future research might explore how hybrid network models, combining NB-IoT and broader 5G architectures, can be applied to enhance UAV performance across varied terrains.

From a network management perspective, using deep learning algorithms for resource optimization and security in 5G-enabled IoT systems has shown promise, particularly in urban environments. Thippeswamy et al. discussed how deep learning enhances resource allocation, reducing latency and improving overall network performance [21]. This approach is relevant to the current study, which incorporated optimization algorithms to adjust UAV power and bandwidth allocation dynamically. However, limitations persist, particularly in addressing real-time adaptations to rapid environmental changes, such as sudden interference in urban areas or unexpected signal attenuation due to physical obstructions. Integrating deep learning into UAV network management frameworks could improve predictive capabilities, allowing systems to preemptively adjust to fluctuations in network demand.

Additionally, this research supports findings from Ageyev et al. investigated traffic aggregation challenges and network planning issues in EPS systems [27]. The present study's optimization models reflect these challenges by addressing the need for seamless traffic management in UAV systems, especially in settings where network congestion is prevalent. However, a notable limitation is the limited adaptability of current traffic control methods to multi-UAV systems in high-traffic areas. Recent advancements in multi-UAV task optimization, as explored by Hung et al., could potentially mitigate this limitation by enabling more efficient UAV coordination and reducing the likelihood of communication bottlenecks [18].

Signal processing and data transmission efficiency are also essential considerations for UAV optimization. Mushtaq et al. compared various OFDM systems and noted the importance of signal processing techniques for mitigating fading effects in noisy environments [28]. This research supports those findings, particularly in urban areas where interference is more pronounced. However, challenges remain in enhancing signal processing for high-speed data applications that involve real-time decision-making. Developing more sophisticated signal processing models for UAV communications, such as those leveraging machine learning to optimize data transmission paths, could address these issues and improve stability in real-time applications.

Another significant area of comparison is energy efficiency. Qasim et al. analyzed methods for improving energy efficiency in digital broadcasting, which is highly relevant for UAV operations where energy conservation is critical for extending flight durations [19]. Although the current study prioritizes stability, energy optimization remains a secondary outcome, suggesting a gap in research that thoroughly integrates energy efficiency into UAV stability models. Addressing this gap could involve employing energy-efficient communication protocols, such as low-power wide-area networks (LPWAN), within urban UAV networks, reducing power consumption without compromising performance.

Furthermore, Sieliukov et al. proposed a conceptual model for mobile communication networks that underscores the importance of adaptability in fluctuating environments [24]. This concept aligns with the current study's emphasis on dynamic optimization models; however, scalability issues limit the application of such models to larger urban networks. Expanding on Sieliukov's work, future research could investigate scalable solutions that maintain UAV stability across diverse urban topographies while adjusting to real-time environmental changes.

Despite these advancements, limitations exist within this study, particularly regarding the scalability of the proposed optimization algorithms and their adaptability to unexpected network disruptions [29]. Additionally, while the models demonstrate significant performance improvements, the impact of these optimizations on UAV battery life and operational sustainability remains underexplored. Integrating energy-efficient algorithms or adaptive power management strategies could enhance the applicability of these findings in extended UAV deployments, especially in settings where continuous operation is required [30].

In conclusion, the present study offers valuable insights into optimizing UAV stability using 5G technology, with findings that corroborate and build upon existing research. While the study addresses key performance metrics, limitations in scalability, real-time adaptability, and energy optimization reveal opportunities for further investigation. Future research should focus on integrating advanced machine learning techniques, hybrid network models, and energy-efficient protocols to fully realize the potential of UAVs in urban and rural environments. This approach would not only enhance UAV performance but also contribute to the sustainable development of smart city infrastructures, supporting both current and emerging UAV applications.

CONCLUSION

The article presents a comprehensive analysis of optimizing UAV stability through 5G technology, emphasizing critical metrics such as latency, signal strength, and bandwidth utilization. By employing advanced statistical and optimization models, the research highlights the significant role that 5G networks play in enhancing UAV performance across diverse environmental conditions, particularly in urban and rural settings. The findings demonstrate that 5G-enabled UAVs can achieve improved stability and efficiency through dynamic resource allocation and trajectory optimization, which are essential for applications in smart cities, disaster response, and environmental monitoring.

The study's approach of utilizing real-time data analysis to adjust UAV network parameters represents a novel contribution to the field. Unlike previous studies that have focused primarily on isolated aspects of UAV functionality, this research integrates multiple performance metrics, offering a holistic understanding of how 5G technology can be leveraged to optimize UAV operations. The use of optimization algorithms such as gradient descent, coupled with predictive models for trajectory and bandwidth allocation, allows UAV systems to respond to environmental fluctuations dynamically. This adaptive approach provides an efficient solution for managing the challenges that UAVs face in high-interference urban areas, where maintaining stable communication is crucial for effective operation.

While the study achieves considerable advancements, it also identifies areas for further research. One limitation observed is the scalability of the current models to larger networks with multiple UAVs operating simultaneously. Urban environments, in particular, pose unique challenges due to high-density infrastructure and frequent signal obstructions. Future research should focus on developing scalable optimization models capable of supporting multi-UAV deployments within such complex environments. Additionally, implementing machine learning techniques for predictive network management could further enhance the adaptability of UAV systems, allowing them to proactively respond to anticipated changes in signal strength and latency.

Another area for future exploration is energy efficiency. Although the research demonstrates improved UAV stability, the impact of these optimizations on energy consumption was not fully explored. Given that energy efficiency is critical for extended UAV operations, future studies could integrate energy management algorithms that minimize power usage without compromising performance. Such an approach would be particularly beneficial in applications where UAVs are required to operate continuously over long durations, such as in agricultural monitoring or border surveillance.

The study also lays the groundwork for exploring hybrid network models that combine 5G with other wireless communication technologies. Hybrid models could offer enhanced connectivity for UAVs in areas where 5G infrastructure is limited, thereby extending the operational range and versatility of UAVs. As 5G networks continue to expand, the integration of additional communication protocols, such as narrowband IoT and low-power wide-area networks, could facilitate seamless UAV operation across both urban and rural areas.

In terms of novelty, the research contributes a unique perspective by linking UAV stability directly with real-time 5G network optimization. This real-time approach is particularly innovative, as it enables UAVs to make instantaneous adjustments to network parameters based on environmental data. The adaptive models developed in this study represent a significant step forward in UAV technology, offering practical solutions for enhancing stability and performance in dynamic settings. By addressing both urban and rural applications, the study demonstrates the versatility of 5G technology in optimizing UAV functions for a wide range of use cases.

The article provides valuable insights into the optimization of UAV systems through 5G technology, with implications for both current and future UAV applications. The integration of predictive models and optimization algorithms not only enhances UAV stability but also opens new possibilities for deploying UAVs in complex environments. As technology continues to advance, further research into scalable, energy-efficient, and hybrid communication solutions will be essential to fully realize the potential of UAVs in various sectors, from smart cities to environmental conservation.

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Статистична оптимізація стабільності БПЛА через параметри мережі 5G

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Анотація. Довідка: дрони, або безпілотні літальні апарати (БПЛА), набули популярності в різних галузях завдяки своїй універсальності та ефективності. Однак досягнення оптимальної стабільності під час польоту залишається проблемою, особливо в динамічних середовищах. Поява технології 5G

з її високошвидкісними можливостями з малою затримкою дає можливість покращити контроль і стабільність безпілотників завдяки передачі даних у реальному часі та оперативним налаштуванням.

Мета: це дослідження вивчає застосування статистичних методів для оптимізації балансу дронів через підключення 5G, зосереджуючись на ключових параметрах мережі, таких як затримка, потужність сигналу та використання пропускної здатності.

Методи: серію польотів було проведено в різних умовах навколишнього середовища, щоб зібрати дані про показники стійкості дрона, включаючи крен, тангаж і поворот. Статистичний аналіз, включаючи регресійні моделі та аналіз часових рядів, було застосовано для оцінки зв'язку між параметрами 5G і балансом дронів. Потім були використані алгоритми оптимізації для динамічного налаштування параметрів мережі з метою підвищення стабільності в режимі реального часу.

Результати. Отримані дані вказують на те, що затримка та потужність сигналу є значущими показниками стабільності дрона, причому менша затримка та оптимізована потужність сигналу корелюють із покращеним балансом. Крім того, оптимізація пропускної здатності сприяла більш плавному керуванню польотом завдяки пріоритетності основних потоків даних.

Висновок: статистичні методи відіграють вирішальну роль у максимізації переваг технології 5G для стабільності дронів. Завдяки точному налаштуванню параметрів 5G дрони можуть підтримувати кращий баланс, підвищуючи загальну ефективність і надійність.

Ключові слова: дрони, БПЛА, 5G, статистична оптимізація, затримка, потужність сигналу, пропускна здатність, моніторинг у реальному часі, оптимізація мережі, стабільність БПЛА.