

Research Article

UAV-Enhanced Coverage Analysis for Cellular Networks at Various Altitudes

O. Alshalabi^{1,*}, N. L. Mohd Kamal², Z. Sahwee³, N. Norhashim⁴, and S. Ahmad Shah⁵

¹ Unmanned Aerial System Research Laboratory, Avionics Section, Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, Malaysia; alshalabi.omran@s.unikl.edu.my;  ORCID ID (<https://orcid.org/0000-0001-7139-7867>)

² Unmanned Aerial System Research Laboratory, Avionics Section, Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, Malaysia; nadhiyalianamk@unikl.edu.my;  ORCID ID (<https://orcid.org/0000-0003-3560-6101>)

³ Unmanned Aerial System Research Laboratory, Avionics Section, Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, Malaysia; zulhilmy@unikl.edu.my;  ORCID ID (<https://orcid.org/0000-0003-4521-8110>)

⁴ Unmanned Aerial System Research Laboratory, Avionics Section, Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, Malaysia; nurhakimah@unikl.edu.my;  ORCID ID (<https://orcid.org/0000-0001-9063-4813>)

⁵ Unmanned Aerial System Research Laboratory, Avionics Section, Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, Malaysia; shahrul@unikl.edu.my;  ORCID ID (<https://orcid.org/0000-0001-9790-9023>)

* Correspondence: alshalabi.omran@s.unikl.edu.my; +601161120506.

Abstract: The increase utilization of Unmanned Aerial Vehicles (UAVs) in Malaysia across diverse sectors necessitates robust communication capabilities for reliable long-distance links. While direct link radio frequencies are commonly employed, their limited range poses challenges for numerous applications. This paper explores the feasibility of leveraging cellular communication to enhance UAV communication capabilities. Field tests conducted in rural areas of Malaysia focus on the radiation patterns of cellular base station antennas at varying altitudes. Results reveal distinctive patterns in Reference Signal Received Power (RSRP) for different altitudes and telecommunication operators. Across all three operators, optimal RSRP values are consistently achieved at 50m altitude. These findings underscore the potential of cellular-connected UAV technology, suggesting directions for further improvements, such as antenna design enhancements on the UAV side.

Keywords: Unmanned Aerial Vehicles (UAVs); Cellular Communication; RSRP; Antenna.



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1. INTRODUCTION

In recent years, there has been a significant surge in the application of Unmanned Aerial Vehicles (UAVs) in Malaysia, as evidenced by the expanding body of research involving both local and international institutions. UAVs are now employed across a spectrum of disciplines within Malaysia, encompassing agriculture, mapping, forestry, river monitoring, transportation, construction, coastal management, flood management, and various other applications (Gohari et al., 2023; Mohd Kamal et al., 2019). With such diverse applications, there arises a pressing need to enhance the communication capabilities of UAVs, enabling them to establish reliable long-distance communication links that extend beyond visual line of sight. While the common approach for UAV communication relies on direct link

radio frequencies in the ISM band, it's important to note that direct link communication typically has a limited range of just a few kilometers, which may not be optimal for many of these applications (Vegni et al., 2021).

On the other hand, cellular communication offers an extensive range with a well-established infrastructure that has been in use for many years. Therefore, the utilization of this advanced technology for UAV communication presents a compelling opportunity to enhance communication links, potentially extending their reach limit to become boundless (Fotouhi et al., 2019). However, it's important to note that cellular technology was originally designed to cater to ground users (Yang et al., 2019), raising questions about its suitability for aerial applications.

Few research has examined the feasibility of using cellular base stations to serve UAVs in Malaysia (Alshalabi et al., 2022; Mohd Kamal et al., 2022). Nevertheless, more extensive field testing is necessary to provide a comprehensive overview of the radiation pattern of these base station antennas, particularly at higher altitudes (Muruganathan et al., 2021). In this paper, we present the results of field tests carried out in rural areas of Malaysia to offer valuable insights into the radiation pattern of cellular base station antennas.

2. METHOD & MATERIAL

The experiment was conducted within a rural location in Malaysia, specifically in Sekinchan, encompassing a round trip distance of 6 km at three distinct altitudes: ground level, 50 meters above ground level, and 100 meters above ground level. The aerial phase of the investigation involved the utilization of Unmanned Aerial Vehicles (UAVs) capable of carrying three mobile phones simultaneously, traversing a distance of 6 km as depicted in Figure 1.



Figure 1. The placement of three phones within the UAV Nose.

Each mobile phone was connected to one of the three major telecommunication operators in Malaysia, namely Celcom, Digi, and Maxis. The mobile phones were equipped with the "NetMonitor Cell Signal Logging" application, facilitating the continuous collection of Reference Signal Received Power (RSRP) data. Furthermore, the spatial coordinates, specifically latitude and longitude, were concurrently recorded as depicted in Figure 2.

The terrestrial experimentation was conducted employing an automotive vehicle carrying the same three mobile phones as seen in Figure 3, heading unidirectionally to establish a baseline reference to ascertain variations in results across different altitudes to assess the optimal telecommunication operator performance at ground level.

An additional terrestrial assessment was conducted to calibrate the three mobile phones. It is recognized that diverse phones exhibit variations in antenna gain; hence, a calibration process was implemented as a preliminary step preceding the result analysis. The calibration procedure comprised three rounds utilizing the same telecommunication operator (Celcom) but employing distinct mobile phones refer to Figure 4. This allowed for a clear clarification of variations in antenna gain across

diverse mobile devices. Subsequently, one of these three mobile devices was selected as a reference, and a constant RSRP value were incorporated into the results of the other two phones to achieve a standardized calibration outcome.



Figure 2. NetMonitor Cell Signal Logging Lite application interact page



Figure 3. Ground Test Utilizing Three Phones Simultaneously



Figure 4. Captured during the Calibration Process in One of the 3 Rounds

3. FINDINGS

Throughout the test, the NetMonitor Cell application reported the primary Long-Term Evolution (LTE) metrics measured at intervals of 100 milliseconds, corresponding to the selected altitude. An important aspect of LTE technology involves reference signals, which a user equipment (UE) utilizes to assess the state of its connection to a given cell tower. RSRP values representing the measured power of LTE reference signals spread across the broadband and narrowband portions of the spectrum. RSRP values, expressed in dBm, are always negative, and a higher value, closer to zero,

indicates a stronger signal. This section is dedicated to presenting the RSRP data, clarifying the radiation characteristics of cellular base station antennas at varying altitudes. It showcases the Empirical Cumulative Distributed Function (ECDF) of the recorded RSRP for different altitudes.

3.1 RSRP Data Record

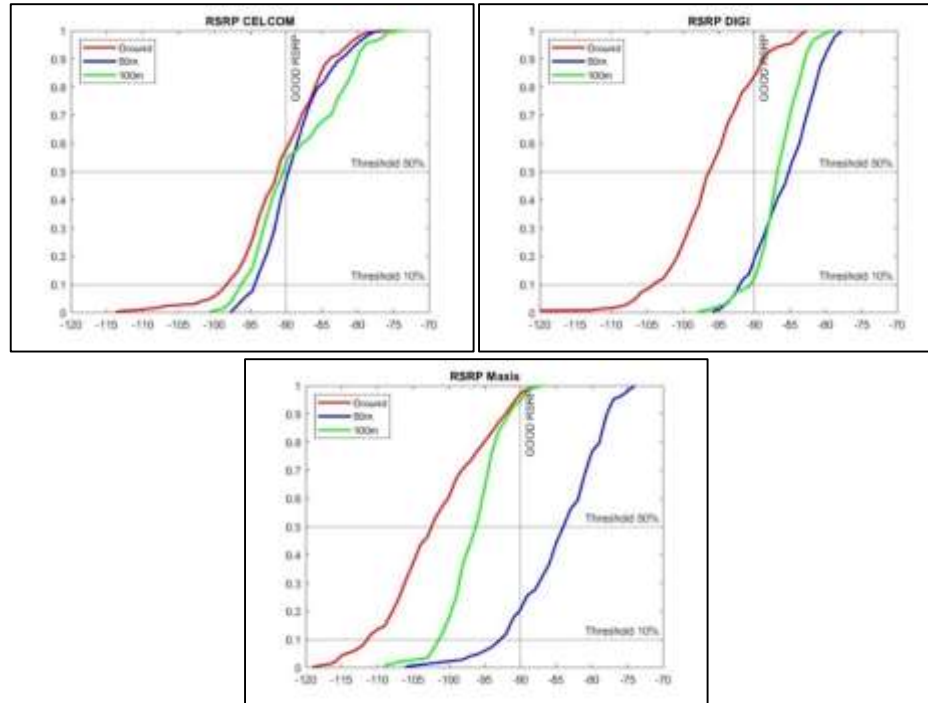


Figure 5. ECDF of RSRP data at three altitude (ground level, 50m, 100m) for three operators. a) Celcom, b) Digi, c) Maxis

Figure 5 shows the ECDF of RSRP data at three altitudes for three operators. From Figure 5, ground test results reveal that in the data collection area, Celcom was the most reliable service provider and hardly any poor service is seen at ground level, but about half the data shows marginal service. Digi has 20% poor service at ground level, none at 50m or 100m, and 60% marginal service at ground, reducing to around 10% at 50m and 100m. Maxis has 60% poor service and about 30% marginal at ground but nearly 0% poor services and 20% marginal at 50m height, while at 100m about 20% poor services and 80% marginal services. Overall, the findings across all three operators suggest that the optimal RSRP value can be achieved at a height of 50m, followed by 100m, and finally, at ground level.

4. DISCUSSION

The obtained results are promising, indicating a high potential for the implementation of Cellular-connected UAV technology. The findings reveal that, across all operators, the coverage at higher altitudes exceeded that at ground level. This improvement is attributed to the absence of obstacles and the unobstructed line of sight between UE and LTE towers at elevated altitudes. However, an interesting observation emerged as the UAV ascended beyond 50m, where the coverage began to decrease due to high potential for path loss at elevated altitudes. The experimental approach involved the integration of a smartphone within a UAV during flight, utilizing ground UE for data collection relevant to aerial UE performance. This methodological choice not only validates the feasibility of Cellular-connected UAVs but also serves as a means to pinpoint areas necessitating refinement in UE performance within aerial contexts. An avenue for potential improvement lies in the

optimization of antenna design. Specifically, substituting omnidirectional antennas, common in ground UEs, with directional antennas for UAVs holds the promise of significantly enhancing performance across diverse altitudes.

5. CONCLUSION

In conclusion, our study highlights the potential of integrating cellular networks to enhance UAV communication. Through field tests conducted at diverse altitudes, the viability of utilizing existing cellular networks for UAV communication is demonstrated. The findings, as presented through ECDF of RSRP data, indicate that RSRP performs optimally at high altitudes, specifically up to 50m. These results underscore the feasibility of Cellular-connected UAV technology. The study suggests avenues for refinement, particularly in the deployment of directional antennas at the UAV-UE side. Overall, this research contributes valuable insights to advancing UAV communication capabilities by presenting a coverage analysis of cellular networks at various altitudes.

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