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Analysis of LTE Network Connection Parameters at Legal Maximum UAV Flight Altitudes and Comparison with Ground

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Abstract

Recently, Unmanned Aerial Vehicles (UAVs) and UAV Traffic Management (UTM) systems have gained attention, particularly for applications such as aerial mapping and agriculture. Due to the widespread use of applications and the increasing number of UAVs, air traffic poses a danger to the public and the inability to track UAVs causes a security vulnerability. The European U-Space concept and the Next GEN concept in the USA implement the Air corridor and UTM system for Tracking of UAVs and Commercial UAVs services. It is desired to use new generation communication infrastructures for UAVs to communicate with UTM uninterruptedly and safely. In this study, flights were conducted at the maximum legal altitude limit of 120 meters to test the usability of the UAV and UTM communication infrastructures of the Long-Term Evolution (LTE) communication infrastructures of Mobile Operators in Turkey. In the study, an LTE-supported UAV was connected to the Türk Telekom Corporation (Türk Telekomünikasyon A.Ş.) Mobile LTE network, log telemetry information was sent to the UTM server on the ground via the UAV from an altitude of 120 meters, and the connection quality of the Mobile Operator was determined. In addition, the signal quality and strength measured from the ground on the same route as the highway were compared with the signal quality and strength received by the UAV at an altitude of 120 meters. Successful results were achieved and it was proven that communication can be achieved using the Mobile Operator's LTE network even at the maximum legal UAV altitude limit.

1. Introduction

With today's technological advancement, Unmanned Aerial Vehicles (UAVs) are widely used in various sectors to increase efficiency and offer new possibilities. These UAVs are equipped with advanced electronic systems and software technologies, and are produced in different concepts and designed to be flexible enough to meet various needs (Gupta et al., 2015). To ensure safe flights, they are supported by reliable flight control systems and constantly developed software support. However, the use of UAVs is becoming increasingly diversified and widespread (Konar et al., 2021; Lin et al., 2018). While they are used in tasks such as detection of plant diseases, field monitoring and fire control in fields such as agriculture and forestry, they also play an important role in the security and defense sector for reconnaissance, surveillance and target identification (Dalkıran et al., 2021; Oktay et al., 2016). The fast and flexible maneuvering capabilities of UAVs provide different advantages over traditional aircraft and human-powered vehicles (Ding et al., 2017). Therefore, with the advancement of UAV technologies and the expansion of their usage areas, these vehicles are expected to gain even more importance in the future.

Unmanned Aerial Vehicles (UAVs) are flown autonomously by users, either remotely controlled directly from the ground station or via predetermined routes and missions (Gharib et al., 2021). In recent years, the increase in demand for UAVs has led to the expansion of their usage areas. UAVs, which were initially used in military operations, later became widespread in civilian areas due to their low operating costs and ease of use. Civilian (hobby and commercial) and professional use of scientific applications is rapidly increasing worldwide (Amorim et al., 2017; Sae et al., 2019). Examples of civilian purposes include intelligence and security activities, weather monitoring, creating three-dimensional models of cities, monitoring fires, monitoring coastal areas, conducting search and rescue operations, analyzing agricultural areas, monitoring natural disasters and infrastructure (Sundaresan et al., 2018; Hellaoui et al., 2020). UAVs are also used for various purposes such as conducting archaeological studies, examining urban transformation and detecting pollution through cartography (Militaru et al., 2020; Nguyen et al., 2017).

Despite the developing UAV and UAV technologies, their usage areas are increasingly diversifying (Watts et al., 2012). However, the rapid increase in the number of UAVs poses a serious security concern for air traffic, and the inability to track them poses a major risk to commercial airspace and people (Qazi et al., 2015). Therefore, various organizations at the international level have seen the need to make new regulations for the registration and monitoring of UAVs. In this context, institutions such as ICAO, FAA in the USA and EASA in the EU have taken steps to regulate UAVs (Ranjan et al., 2018).

In order for UAVs to be recorded and monitored by the Unmanned Aircraft System Traffic Management (UTM) system, the importance of the services provided by mobile GSM operators and therefore mobile networks is increasing (Batistatos et al., 2018; Horani et al., 2018). The concept of recording and tracking drones in UTM by connecting to the mobile network with UAV communication support based on LTE standards stands out as a forward-looking approach (Lee et al., 2019).

For UAVs to be registered and monitored by UTM, the services provided by Mobile GSM Operators and therefore mobile networks have gained importance (Karamchedu, 2020). With the UAV communication support that comes with LTE standards, the concept of registering and following the drones to the UTM by connecting to the mobile network has been established (Miao et al., 2019; Ding et al., 2017; Stanczak et al., 2018; Reingruber et al., 2022).

In a previous study, the effects on network performance were investigated in terms of data outputs that would be possible with realistic deployment and mobility models encountered in a simulated environment in Aerial UAV-based building surveillance networks but in real-world UAV-based environments (Watts et al., 2012). Another study investigated realistic propagation and mobility models present in real-world UAV-based environments. It examined the effects of these models on the network performance of Airborne UAV-based building surveillance networks in a simulated environment, in terms of possible data outputs (Qazi et al., 2015). Another study examined the impact of the base station's maximum capacity, cell's automatic switching performance, and UAVs' range of action on the communication performance of the system. The research suggests that implementing LTE private network technology in a group of UAVs is viable and provides considerable benefits, such as great versatility, affordability, and excellent signal quality (Ding et al., 2017). Unmanned aerial vehicles function as airborne relay stations, providing tele-communications services to areas with limited connectivity. Furthermore, they serve as backup data gateways when base stations become overloaded due to increased traffic. The study presents representative findings obtained through a two-year measurement campaign that utilized quadcopters in various operational scenarios. This examination evaluated the strength of the Long-Term Evolution (LTE) signal and the Signal-to-Interference-plus-Noise Ratio (SINR) in the atmosphere across two different configurations. The study area consisted of an underserved rural region and the urban centre of a town. High SINR levels (>10 dB) were recorded at certain heights in the rural scenario, allowing for an expansion of the network coverage. In the urban environment, the ascending UAV captures more cells, leading to an influence on the SINR values. Nonetheless, it has the potential to promote diversity on a larger scale (Batistatos et al., 2018). Another study has developed a visualization tool for LTE based surveillance of UAVs in an urban area (Lee et al., 2019). This study developed a tool to visualize the estimation of UAV positions using LTE signals in an urban area. The visualization tool displays true positions of UAVs and evolved Node Bs (eNodeBs), as well as estimated positions of UAVs, and calculated horizontal and vertical protection levels (HPLs and VPLs) on a 3D city map (Lee et al., 2019). The other study analysed 4G/LTE coverage by implementing a virtual environment simulation of a terrestrial cellular network. This method allowed for the identification and analysis of potential issues when setting up a UAV datalink over 4G networks. This study concludes that an increasing amount of research on unmanned aerial vehicles (UAVs) indicates that terrestrial mobile networks offer the most suitable means of supporting UAV communications at low altitudes. These networks can provide suitable traffic management capabilities to ensure the safe and secure operation of the UAV (Militaru et al., 2020). Another study examines the key features of Direct Communications or Device-to-Device (D2D) communications, as they apply to communication between UAVs (Karamchedu, 2020). Another study investigated the change in performance of a commercially available multi-band LTE antenna when used near a UAV fuselage. This study provides a more thorough comprehension of antenna performance near a UAV. Moreover, these out-comes will assist in enhancing antenna management, mitigating adverse impacts on drone operations at high altitudes exceeding typical cell tower height (Reingruber et al., 2022). Previous studies on UAV telemetry over LTE networks can be broadly categorized into simulation-based research, controlled laboratory studies, and real-world field experiments. Simulation-based studies (e.g., Ding et al., 2017; Karamchedu, 2020) allow for controlled parameter testing but lack terrain-induced variability. Field tests in urban areas (e.g., Lee et al., 2019) often highlight interference and signal congestion, whereas rural-focused studies (e.g., Nguyen et al., 2017) typically rely on ideal flat landscapes. Moreover, a distinction exists between studies using commercial LTE infrastructure and those using private or purpose-built networks.

Despite this progress, there remains a lack of empirical field data under actual regulatory constraints and with real commercial LTE networks in semi-rural environments. Our study addresses this gap by conducting legal-altitude UAV telemetry measurements using Turkey's live LTE infrastructure, in a topographically diverse region (Cappadocia). This approach helps assess signal viability in mixed-use terrains and informs national airspace integration strategies for similar geographies.

While the feasibility of LTE-based UAV telemetry has been explored in previous studies across various international contexts, our study provides a unique real-world validation within Turkey’s regulatory and geographic framework. The test corridor between Mustafapaşa and Ürgüp presents semi-rural topography with non-uniform coverage, offering insights into the LTE network's viability under less idealized conditions. Unlike simulations or urban-focused field tests, our study evaluates commercial LTE performance in a real-use scenario reflecting operational constraints common in many countries adopting similar UAV flight ceilings and regulatory models.

This study is motivated by the expected exponential growth of advanced and autonomous aircraft in the upcoming years. In the future, air traffic management is expected to face increased complexity due to the growing number of aircraft occupying both low and high-altitude airspace. This study is to investigate the usability of communication between UAV and UTM over Türk Telekom Corporation (Türk Telekomünikasyon A.Ş.) Mobile LTE Communication infrastructure. For this purpose, within the scope of the study, flight tests were carried out at 120 meters, which is the legal altitude limit of UAVs determined by the Directorate General of Civil Aviation in Turkey. Flight tests were carried out approximately 5 kilometers between Mustafapaşa and Ürgüp.

Data from 120-meter flight tests and ground tests were compared.

2. Materials and Methods

In this study, flights were made with a specially developed quadcopter that can fly for 10-12 minutes. Pixhawk Cube Black, an advanced and open-source code-supported autopilot, was used for the UAV with its light and strong body and 7000 mAh capacity 4S battery. Data received during the UAV flight can be received with the telemetry module and the TEMS phone placed directly on the UAV.
During the test flights with the UAV, a Samsung S10 TEMS phone, whose placement on the UAV is shown in Figure-1, was used for signal measurement and efficiency tests. Additionally, the Ground control station interface and the UAV route are shown in Figure-1. In addition, the Raspberry Pi 4 Model B control card, which has a wide user base and flexibility of use in different projects, was used. Sixfab 3G/4G LTE Base LINE and Quetel EC 25 Mini PCI 4G/LTE GSM modem were preferred for the UAV to transmit telemetry information via broadband LTE base station.
A total of 4 flight missions were conducted along the same predefined 5 km route between Mustafapaşa and Ürgüp at a legal altitude of 120 meters. Each mission was performed under similar environmental conditions: clear weather, wind speed below 5 m/s, and temperatures ranging from 18°C to 24°C, between 09:00 and 13:00 local time. The drone flew the identical autonomous route in each mission to ensure consistency. Data collection was performed using a Samsung S10 TEMS phone mounted on the UAV, configured via TEMS Pocket software. The sample rate was set to 1 Hz, generating approximately 3,000 data points per flight (totaling around 12,000 samples). Ground tests were performed on the same route by placing the TEMS phone in a stationary vehicle at four designated points (start, 1.5 km, 3 km, end point). The devices used for testing, including the TEMS phone, were verified using standard calibration procedures provided by the manufacturer, and the LTE modem settings were configured to standard operating parameters (Band 20 and Band 3 activation with automatic frequency switching).

Figure 1.TEMS phone, Ground control station interface and UAV route

2.1. Test Methods & Test Scenarios

The tests were carried out in Nevşehir Cappadocia, on the route determined between Mustafapaşa and Ürgüp District. The total route length is 5 km. 3G and LTE infrastructures, different bands and frequencies are available in the test area. LTE band frequencies are 1800-20 MHZ, 800-10 MHZ and WCDMA band frequencies are 900 MHZ, 2100 MHZ.

The UAV and LTE network communication Architecture is planned for the tests to be carried out within the scope of UAV innovation tests. The intended architecture is presented in detail in Figure 2. Within the scope of the architecture, it is aimed to connect the LTE communication kit on the UAV to the LTE Base Stations in a healthy way.
The LTE-supported UAV was connected to Türk Telekom LTE base stations with the Architecture used in the project and successfully sent the telemetry information to the UAV Tracking system at Cappadocia University.

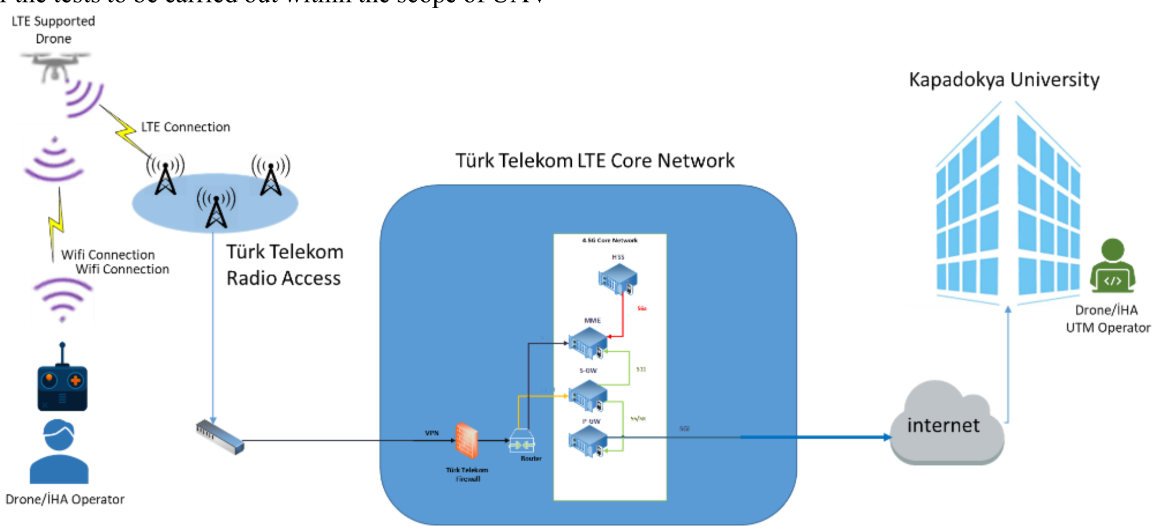

Figure 2. System Architecture

The main purpose of the uplink test is to transfer the telemetry information on the drone to the log server at Cappadocia University over the LTE network. The tests were carried out by generating data traffic over Tems phone and Raspberry pi at the same time with LTE modem support. First of all, with this test, the transmission of the telemetry information of the drone to the on-site server over the LTE network and the throughput scenario were realized. It was connected to Türk Telekom Mobile communication system with LTE-supported UAV. Then, the drone successfully transferred the telemetry information to the Server at Cappadocia University via Türk Telekom LTE base stations. Uplink throughput test topology details can be seen in Figure 3.

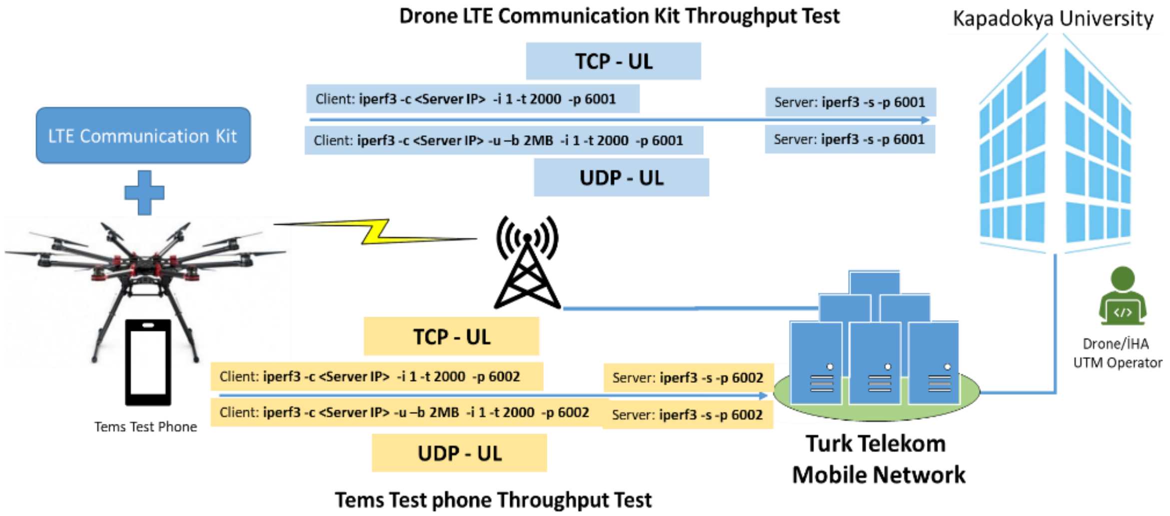

Figure 3.UL Throughput Test Topology

UAV and LTE network communication Architecture is planned for the tests to be carried out within the scope of UAV innovation tests. Within the scope of the architecture, it is aimed to connect the LTE communication kit on the UAV to the LTE Base Stations in a healthy way. The LTE-supported UAV was connected to Türk Telekom LTE base stations with the Architecture used in the project and successfully sent the telemetry information to the UAV Tracking system at Cappadocia University.

3. Result and Discussion

The primary aim of this study was to evaluate the feasibility and basic signal viability of LTE-based telemetry at the legal UAV flight altitude using commercially available infrastructure in a real-world test scenario. As such, the scope of analysis was focused on visual comparison of key LTE parameters (RSRP, RSRQ, SINR) rather than on statistical generalization. The number of flights (n=4) was sufficient for preliminary insights but not intended for robust statistical treatment. In the study, the drone connected to Türk Telekom live mobile LTE network was flown on the determined route and test scenarios were realized. The tests were carried out in Nevşehir Cappadocia on a total of 5 km route determined between Mustafapaşa and Ürgüp District. The drone was tested with 4 different flights (UL-TCP/UDP and DL-TCP/UDP) at an altitude of 120 meters. UDP and TCP test throughput results satisfying for the drone to provide Control Channel information and other metrics.

Within the scope of the regulations issued in Europe and America, UAV Traffic Management Systems were started to be used to manage and expand Commercial UAV air operations. The basic requirement of these systems is the two-way transfer of TCP/UDP Telemetry, which is required for the management and control of UAVs, to ground control systems. This transmission requires reliable and comprehensive wireless communication infrastructures. By this way, UAVs are integrated and managed with UAV Monitoring, Control and Traffic Management Systems (UTM) serving on the Cloud.

In the studies carried out, it has been seen that 4G / LTE communication technologies support the necessary communication infrastructure for UAVs. Especially within the scope of U-Space studies carried out in the European Union, 4G supported UAVs have started to serve commercially in an integrated manner with UTM systems running on the cloud. The 3Gpp standard community has started to publish Mobile Communication systems standards for UAVs that will work with UTM systems.

In the UAV Innovation Project study, a UAV with 4G Mobile Communication kit integration was flown in connection with Türk Telekom live mobile network, UAV Telemetry information was transferred to Cappadocia University servers over Türk Telekom 3G/4G Mobile network and the usability of the network for UAV connected to Türk Telekom Mobile network was tested.

The UAV completed its flight on the highway and by being constantly monitored from the ground in Auto mode. During the flight, flight information was constantly monitored via the ground control station and necessary emergency scenarios (Fail Safe) were planned to avoid accidents. For autonomous flight, an altitude value of 120 meters has been determined, which is the maximum flight altitude determined by the General Directorate of Civil Aviation (SHGM). This value is set in Terrain Following/Holding mode, which can follow the land surface via QGroundControl, an open-source ground control station software.

Some values determining the signal level and quality of the signal for LTE networks obtained as a result of test flights at an altitude of 120 meters are discussed. During one of the test missions, a brief degradation in SINR was observed near the 3.8 km mark of the route, where the SINR temporarily dropped below 0 dB for approximately 6 seconds. Although no complete connection loss occurred, such variations highlight the sensitivity of UAV telemetry to local network coverage and environmental factors. These observations are consistent with the expected fluctuations in semi-rural LTE deployments. Reference-Signal-Receive-Power (RSRP) and Reference Signal Received Quality (RSRQ) values are two different parameters aimed in this study. While RSRP defines the strength of LTE Reference Signals spanning full bandwidth and narrow band, RSRQ defines the quality of the received signal. In addition, the parameters that determine the signal level and quality of the signal for LTE networks were compared with ground tests. As a result of the tests performed at a flight altitude of 120 meters and on the ground, the RSRP value for the LTE infrastructure is shown in Figure 4.

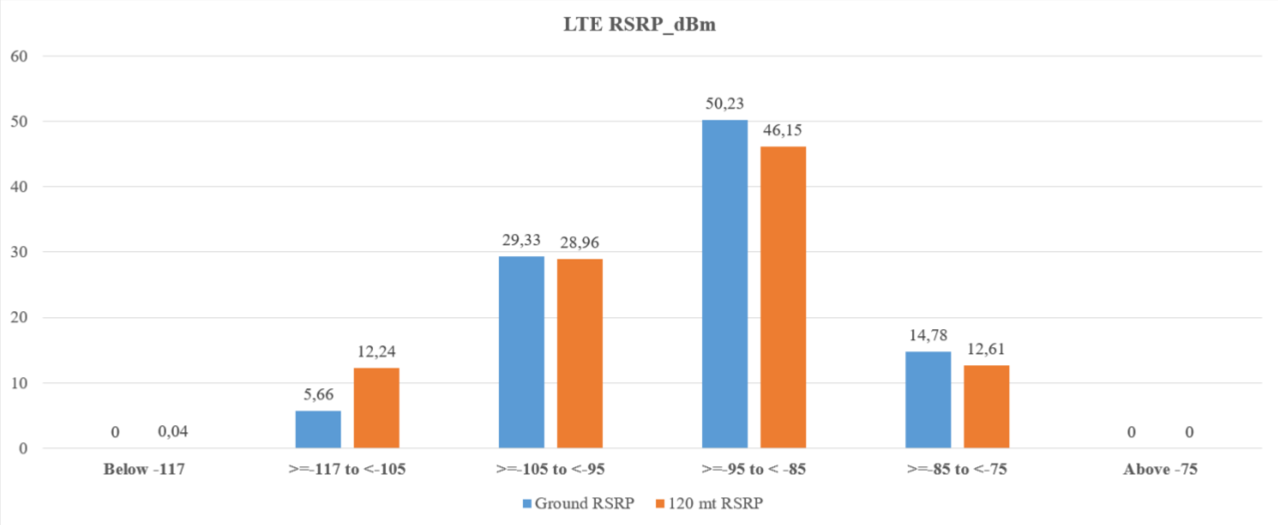

Figure 4. LTE Reference Signal Receive Power (RSRP) at 120 m and Ground,

Flights at 120 meters were carried out at different altitudes with the mobile device used for communication in the free mode of the commercial 3G and 4G network. In addition, the tests were carried out on LTE technology because the mobile network had 3G technology in the test area, there was UDP in the test area and the LTE coverage area was sufficient. Türk Telekom Turkey has 10 MHz spectrum in the 800MHz band, which can provide maximum efficiency of approximately 75Mb/s in the downlink and 25Mb/s in the uplink. In addition, Türk Telekom uses 20 MHz spectrum in the 1800 MHZ band, and this spectrum can provide maximum efficiency of approximately 150 Mbps in the downlink and 50 Mbps in the uplink. Reaching such a high speed is a rare occurrence. The testing tool used to determine throughput without enabling any additional features or optimizations on the network is a Tems Pocket mobile tester that is pre-configured to emulate common device interaction patterns with the mobile network. As a result of the tests, it was seen that Türk Telekom 4G Communication infrastructure successfully supports UAV-TCP data traffic. RSRP, RSRQ and SINR values for Uplink and Downlink are presented for the UAV monitored and managed using the TCP-DL connection. In this study, the results including UAV flight test RSRP, RSRQ and SINR data for cell signal quality serving TCP-DL LTE at an altitude of 120 meters are discussed. In addition, the UAV, which was tested at 120 meters, performed its entire flight over the highway. In this way, continuous visual tracking of the UAV was ensured throughout the flight. In addition, the highway was used for UAV ground tests and the test was aimed to give more accurate results by following the same route. While the overall telemetry performance was within acceptable levels, some edge cases may pose operational risks in real-world scenarios. For instance, LTE signal strength and SINR can degrade sharply due to terrain obstructions, sudden weather changes (e.g., precipitation or high humidity), or network congestion during peak hours. Although no critical failures were observed in our tests, a brief SINR drop below 0 dB near the 3.8 km mark highlights the potential for intermittent telemetry disruptions. In practical UAV deployments, such interruptions may impact command-and-control reliability, particularly in beyond visual line-of-sight (BVLOS) operations. These caveats suggest the need for fail-safe procedures and redundancy mechanisms when relying solely on commercial LTE networks.

Compared to UTM pilot projects in Europe (e.g., SESAR U-space trials) and the USA (e.g., NASA's UTM initiative), our study is limited in scope but provides practical insight from a localized operational context. Unlike those projects which involve multi-layer airspace integration and often rely on custom communication infrastructure, our test used standard commercial LTE service without priority access or UAV-specific tuning. This reflects a "worst-case" scenario and helps assess LTE viability without specialized support. Future work should involve multi-operator testing, UAV-specific LTE QoS modifications, and integration with cloud-based dynamic UTM platforms. Regulatory bodies may also need to explore spectrum reservation or slicing for UAV operations to ensure real-time communication quality and predictability.

Many measurements and evaluations can be made to evaluate the quality of the wireless communication signal. In this study, the most basic indicators RSRQ, RSRP and SINR were examined and compared. Figure 4 shows the RSRP values measured in 120 meter flight and ground tests. The blue indicator represents ground tests and the orange indicator represents 120 meter flight tests.

RSRP plays a crucial role in evaluating the quality of cellular connections and is an important indicator for optimizing network performance. Reference Signal Received Power (RSRP) represents how strong the connection between the cell and the base station is in wireless communication. RSRP expresses power in decibels (dBm). It can take values between -130 dBm and -50 dBm, and less negative values indicate stronger signal strength. RSRP is an important parameter for network operators to evaluate the quality and coverage of their cellular networks. Figure 4 shows the quality of cellular networks at the UAV maximum legal altitude of Türk Telekom LTE Mobile communication infrastructure.

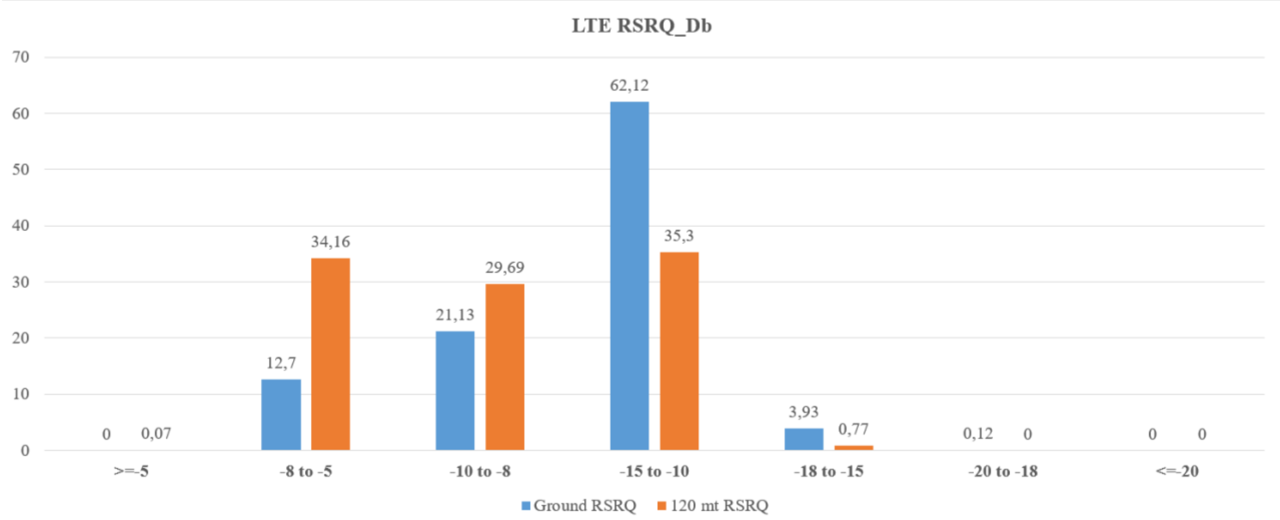

Figure 5. LTE Reference Signal Received Quality (RSRQ) at 120 m and Ground

RSRQ, which is an important parameter in wireless communication systems, especially in cellular networks such as 4G LTE and 5G, measures the quality of the signal that a serving cell receives from the base station. While the RSRP value measures the signal strength, the RSRQ value evaluates the level of interference and noise in the received signal. RSRQ values obtained in the tests are shown in Figure 5. Here, blue color represents ground tests and orange color represents values obtained from 120 meter flights. RSRQ operating values range from -3 dB to -18 dB, with higher values indicating a more suitable RSRQ and better signal quality.

RSRQ provides a comprehensive analysis of signal quality by combining both signal strength (RSRP) and the level of interference from other nearby cells. RSRQ data provides crucial information for network operators to optimize their cellular networks. Thus, operators can easily identify areas where interference may occur by analyzing RSRQ values in different locations. In addition to all this, RSRQ helps mobile devices select cells for the best communication.

An important parameter in the wireless communication system for mobile operators is Signal-to-Interference-plus-Noise Ratio (SINR). This measurement parameter represents the quality of the RF channel. SINR indicates the ratio between received power and interference in Decibels (dB). SINR shows the signal quality depending on Signal Power (S), Interference Power (I) and Noise Power (N) values. Figure 6 shows the SINR values obtained in this study. SINR values obtained in ground tests are shown in blue and SINR values obtained after 120 meters flight are shown in orange.

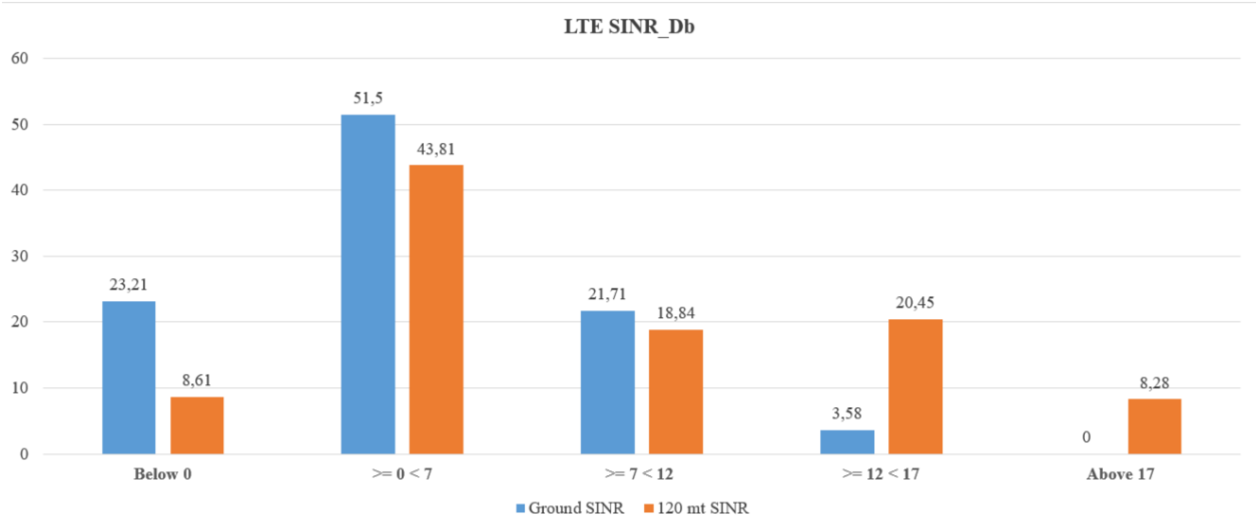

Figure 6. LTE Signal-to-Interference-plus-Noise Ratio (SINR) at 120 m and Ground

SINR describes mobile network throughput and network coverage and capacity. Mobile network operators can reduce network load by improving SINR values. The value scale is presented in Figure 7 to understand how the RSRP, RSRQ and SINR parameters are specified according to their levels.

	RSRP (dBm)	RSRQ (dB)	SINR (dB)
BAD	< -105	< -15	< 5
FAIR	-95 to -105	-10 to -15	5 to 20
GOOD	> -95	> -10	> 20

Figure 7. Scale of parameters RSRP, RSRQ and SINR

Within the scope of the study, flight tests were carried out with the Tems Phone placed on the UAV at a legal altitude of 120 meters. RSRP, RSRQ and SINR parameters were recorded for examination throughout the flights. Figures 4, 5, and 6 showed the results of RSRP, RSRQ, and SINR, respectively. In addition, one of the main purposes of the study is to measure RSRP, RSRQ and SINR values by monitoring the route followed on the ground during the flight. Thus, the signal values of base stations normally developed for ground level wireless communication were tested. Considering these values, the main purpose of this study is to see how they change during flights at 120 meters. For this purpose, in order to compare the measurements, both the maximum UAV flight altitude and the minimum flight altitude were made within acceptable limits in the graphics.

4. Conclusion

UAV Traffic Management Systems are being tested in many regions, especially in Europe and America, in order to manage UAV air operations, which are becoming more widespread day by day in the world. The basic requirement of these systems is the two-way transfer of TCP/UDP Telemetry, which is required for the management and control of UAVs, to ground control systems. This transmission requires reliable and comprehensive wireless communication infrastructures.

In this study, it has been proven that the infrastructure of 4G/LTE communication technologies supports the tests carried out at ground level and at 120 meters, which is the legal altitude limit specified in Turkey for UAV systems. Tests were carried out at minimum and maximum legal altitude to determine how communication capability would change. As a result of the tests carried out within the scope of the UAV Innovation Project carried out in partnership with Türk Telekom, Argela and Cappadocia University, the UAV with 4G Mobile Communication kit integration in connection with the Türk Telekom live mobile network successfully performed flights. Telemetry information was transferred and made available to Cappadocia University servers via Türk Telekom 3G/4G Mobile network. The study proved that UAV Traffic Management Systems can be used successfully at the legal minimum and maximum UAV altitudes in Turkey and that RSRQ, RSRP and SINR parameters will support this telemetry communication. Although the experiments were conducted within the Turkish regulatory environment, the findings are relevant to regions with comparable LTE infrastructure and regulatory limits on UAV altitudes. The results may guide policy decisions and infrastructure assessments in similar semi-urban or rural geographies where LTE-based UTM integration is being considered. Within the scope of the UAV Innovation Project, it aims to strengthen its background by carrying out similar studies at certain altitudes between 0 and 120 meters in the following phases. One limitation of the present study is the lack of statistical generalization and the exclusive use of a single operator. Future studies will aim to include a larger number of flights, multiple LTE service providers, diverse terrain types, and statistical treatment of signal performance to further strengthen the generalizability of the findings.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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