

Towards a 5G Equipped Video Surveillance UAV for Public Safety

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Abstract: South Africa faces a severe crime problem, with persistent issues such as murder, hijacking, and CIT heists. This research examines existing surveillance strategies, including UAVs, and identifies their limitations. To address these shortcomings, we propose a novel solution that leverages 5G technology to enhance UAV capabilities, offering low latency and high bandwidth for improved surveillance. Our solution introduces a hybrid-VTOL surveillance UAV integrated with predictive policing techniques. Machine learning algorithms and statistical analysis will be employed to forecast crime-prone areas, enabling strategic UAV deployment. We will develop and evaluate this solution utilizing a CSIR-developed 5G testbed, focusing on Quality of Service (QoS) metrics. A UAV equipped with a 4K camera will act as User Equipment (UE), with functionality assessments carried out from a ground control station (GCS). Key performance indicators like RSRP (Reference Signal Received Power), RSRQ (Reference Signal Received Quality), RSSI (Reference Signal Strength Indicator), packet loss, throughput, and control latency will measure the solution's effectiveness and its potential to make a positive impact on societal safety.

Keywords: Surveillance, Radio Access Network, RAN, 5G, Public Safety, Crime, UAV, Drone, Unmanned Aerial Vehicle, Predictive Policing

1. Introduction

South Africa is among countries with a high crime rate. Crimes such as murder, vehicle hijacking, robbery, and Cash in Transit (CIT) heists are some of the common crimes that society faces daily. It has been estimated that there were about 1,520,000 incidents of theft of personal property in the year 2022/23, which affected 1,228,000 people who are 16 years of age or older [1]. The police have recorded 6,228 counts of murder between April 2023 and June 2023, and about 1,188 of these murder counts were women and children. Many of these people were murdered in public spaces during arguments, in an act of vigilantism, or murdered while being robbed [2]. Hijacking remains a major concern, with around 128,000 vehicles hijacked on public roads in 2022/23 [2]. Cash in Transit (CIT) heists are also in a state of influx. They can result in fatalities such as the murder of private security personnel and civilians near the crime incident. This is a major concern because it indicates a lack of police presence or visibility in public spaces. The perpetrators of contact crimes gain confidence in knowing that they are not watched or monitored. The criminals are less likely to commit a crime if they know that they are being monitored, and this theory is commonly known as Perceptual Deterrence in criminology [3]. Crime has also been associated with changing weather conditions. There is sufficient evidence that shows correlation between crime and different weather conditions. The association between crime and weather conditions for the township of Khayelitsha in the Western Cape has been studied for over a decade. It has been found that the risk of violent crimes increases by up to 32% for temperatures greater than 25°C which are hot days, and the risk of property crime increase

by up to **50%** for temperatures less than **7°C** which are cold days and up to **40%** on rainy days [4]. The evidence in this section shows that crime is a major concern needing intervention.

The high crime rate in South Africa poses a significant threat to the well-being and safety of its citizens, creating a critical need for urgent and comprehensive intervention. Crime paints a devastating picture in South Africa: widespread theft, shocking murders of women and children, terrifying carjackings, and brazen cash-in-transit robberies. These crimes undermine public trust, deter investment, and perpetuate a cycle of trauma and fear within communities.

The psychological impact of this constant threat should not be underestimated. The lack of police presence erodes public confidence and can embolden criminals. Furthermore, the correlation between weather patterns and crime rates underscores the complex interplay of social and environmental factors contributing to criminal activity. Therefore, addressing crime in South Africa requires a multifaceted approach that considers not only policing strategies but also socioeconomic factors and community-based interventions. This paper aims to present a cost-effective solution applicable to law enforcement or government agencies for crime reduction. The proposed solution will primarily target metropolitan cities, given their observed higher crime rates compared to other areas.

In Section 2, we delve into current crime reduction solutions and their associated limitations. Section 3 outlines the proposed solution for crime reduction, while Section 4 elucidates the objectives of this paper. Section 5 delineates the methodology employed, and Section 6 is the proof-of-concept validation. In addition, Section 7 recommends metrics and processes for testing the proposed solution, Section 8 discusses the socio-economic benefits it offers. Finally, Section 9 provides the concluding remarks for the paper.

2. Existing Solutions and Their Limitations

2.1 CCTV-based Surveillance and Shortcomings

CCTV cameras are a widely used method for crime prevention in public and private spaces around the world. They are commonly found in residential areas, businesses, and on street corners.

CCTV surveillance has shown mixed results in crime reduction. Studies indicate it led to some decline in crime rates in the US and Britain [5], especially property crimes [5]. In Stockholm subways, it reduced crime by roughly 25%, but the deterrent effect comes at a high cost (approximately \$2000 per prevented crime) [6]. However, a downside is that crime may simply get displaced to unmonitored areas [6]. Plus, traditional CCTV cameras have limitations – they are fixed, creating blind spots, can be vandalized, and criminals may find ways to avoid them [7].

The City of Cape Town relies on roughly ,2345 public cameras owned by various agencies for surveillance. Because of vandalism, the city's CCTV maintenance budget jumped from R9.8 million to R50 million [7]. Tshwane and Johannesburg have fewer cameras in their central areas (319 and 450 respectively), but plan to expand their networks [8]. However, this strategy has limitations. Studies show that cameras may simply push crime to unmonitored areas [6]. Additionally, CCTV cameras are fixed, easily vandalized, and costly to install and maintain [7].

While CCTV cameras have shown some success in reducing crime, especially property crimes, they present several limitations that hinder their effectiveness. Their static nature creates blind spots, making them vulnerable to criminals finding ways to evade them. Additionally, CCTV systems are expensive to maintain due to vandalism and require ongoing upgrades to stay relevant.

Surveillance Unmanned Aerial Vehicles (UAVs), also known as drones, offer a compelling alternative. Unlike fixed CCTV cameras, UAVs can patrol larger areas, navigate intricate spaces, and provide real-time footage with superior coverage, minimizing blind spots. Furthermore, they can adapt to changing situations, offering a more dynamic and comprehensive security solution. While initial acquisition costs of UAVs might be higher, their ability to cover larger areas and require less infrastructure could lead to long-term cost savings compared to extensive CCTV networks. The flexibility and adaptability of UAVs make them a promising alternative for enhancing public safety and addressing the limitations of traditional CCTV surveillance.

2.2 UAV-based Video Surveillance and Shortcomings

Unmanned Aerial Vehicles (UAVs), commonly known as drones have been used for surveillance missions requiring mobility and the sharing of surveillance resources. They have been used in the military, and some of the popular ones are the Predator A which is manufactured by the US General Atomics and The EuroHawk which is manufactured by EADS and Northrop Grumman [9]. These are high altitude, long endurance (“HALE”) types of UAVs. These UAVs are very large in size and have other capabilities such as carrying missiles. This is because military UAVs serve various purposes, including reconnaissance, which involves surveying a region to identify enemy positions, interception, and assessing the effectiveness of combat attacks. They employ advanced propulsion systems and utilise satellite communication systems, contributing to their high cost. In addition, they require launch and landing facilities at airports. The high-altitude, long-endurance UAVs requires a Data-Link that will facilitate direct radio communication between the ground control station (GCS) and the UAV or indirect radio communication via the satellite as shown in Figure 1.

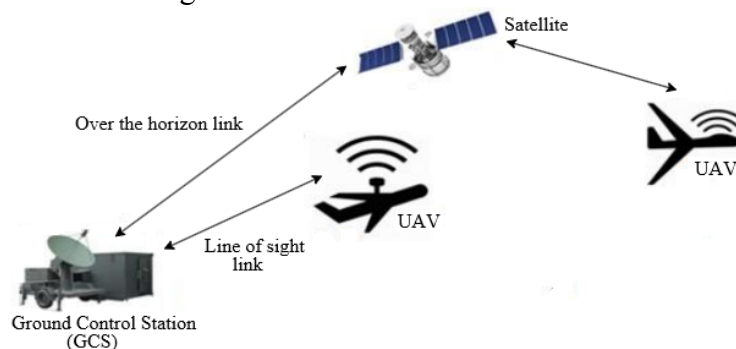


Figure 1: Data-Link communication for a UAV [10]

The unmanned aircraft system above is not suitable for policing applications due to the size and cost of the entire infrastructure. A large size UAV might not be agile enough for complex terrains on the inner city. Issues such as data interception, Data-Link security, and signal latency are attributes that add more complexity to this system.

Alternatively, a cost-effective, miniature, and medium altitude UAV with moderate range can be used. These cost-effective UAVs use Wi-Fi and Bluetooth for communication which have a limited range [11]. A restricted operational range poses a significant drawback for these UAVs, as it exposes them to the risk of being lost in the event of a connection failure. Another challenge concerns the storage of surveillance footage. When the storage medium is mounted on the UAV, losing the UAV results in the inability to recover the footage. These UAVs use point-to-point communication over an unlicensed spectrum which comes with the challenges of relatively low data rates and being prone to interference.

The introduction of UAVs with cellular connectivity helps alleviate these limitations. These UAVs utilise a cellular network instead of point-to-point ground communication on

an unlicensed band. The UAVs are incorporated into the cellular network as user equipment (UE). The compelling benefits of UAVs with cellular connectivity encompass universal accessibility, as cellular networks offer global coverage. The UAV pilot can remotely command and control it from any location near cellular base stations, and videos can be transmitted to receivers located globally. It is easy to monitor cellular-connected UAVs which simplifies air traffic control. UAVs with cellular connectivity exhibit resilient navigation capabilities as they rely on cellular signals instead of the Global Positioning System (GPS) satellites, which can be vulnerable to adverse weather conditions and tall structures [12]. Cellular-connected UAVs are cost-effective in the sense that they leverage the existing cellular infrastructure.

Although cellular-connected UAVs have more connectivity-related benefits, their adoption for video surveillance has encountered resistance owing to limitations in the LTE/4G network. The limitations exist in terms of video quality, bandwidth, data rates, latency, etc. The surveillance UAV's success relies on its capability to efficiently transmit videos to the ground control station. On board storage carries the risk of being lost should the drone lose signal. The mobile network traffic is predominantly driven by video content. Therefore, video experience is a key indicator of the network quality of service (QoS) [13]. Video quality is dependent on the resolution and bit rate, and a higher resolution and bit rate requires higher bandwidth [13]. Therefore, high quality videos captured by the UAV will put a strain on the network and require higher bandwidth at the ground station. Additionally, **10ms** latency is not good enough for the agility and remote control of the UAV. Metropolitan cities tend to have complex terrains which will affect a UAV flying at a lower altitude.

3. Proposed: 5G-based Video Surveillance UAV

The introduction of 5G has sparked interest in applications such as video surveillance because of its benefits over the LTE/4G network. The video quality is better on a 5G network than on an LTE/4G network. Theoretically, the bandwidth of a 5G network can reach beyond 20Gbps, which significantly surpasses that of LTE/4G. The high data rate supports a high resolution of 4K and 8K ultra-high-definition video. The 5G network is capable of ultra-low latency of **1ms**. The improvements in bandwidth mean that high-quality real-time videos can be received at the ground station with minimal delay, and an improved real-time streaming of UAV footage can also be used in live broadcasting applications. The UAV equipped with 5G will attain greater altitude, resulting in a high-latitude ultra-high-definition wide-angle overlook. Pairing the UAV with a 360-degree camera enables multi-dimensional shooting capabilities. This will enable pilots on the ground station to have 360-degree view from a single point, transforming a surveillance UAV into an unbounded eye in the sky. The 5G network will improve position accuracy, meeting the demands of complex urban terrain with numerous high-rise buildings. Figure 2 shows how a video surveillance UAV, pilot, and air traffic controller can be connected with a standalone 5G architecture.

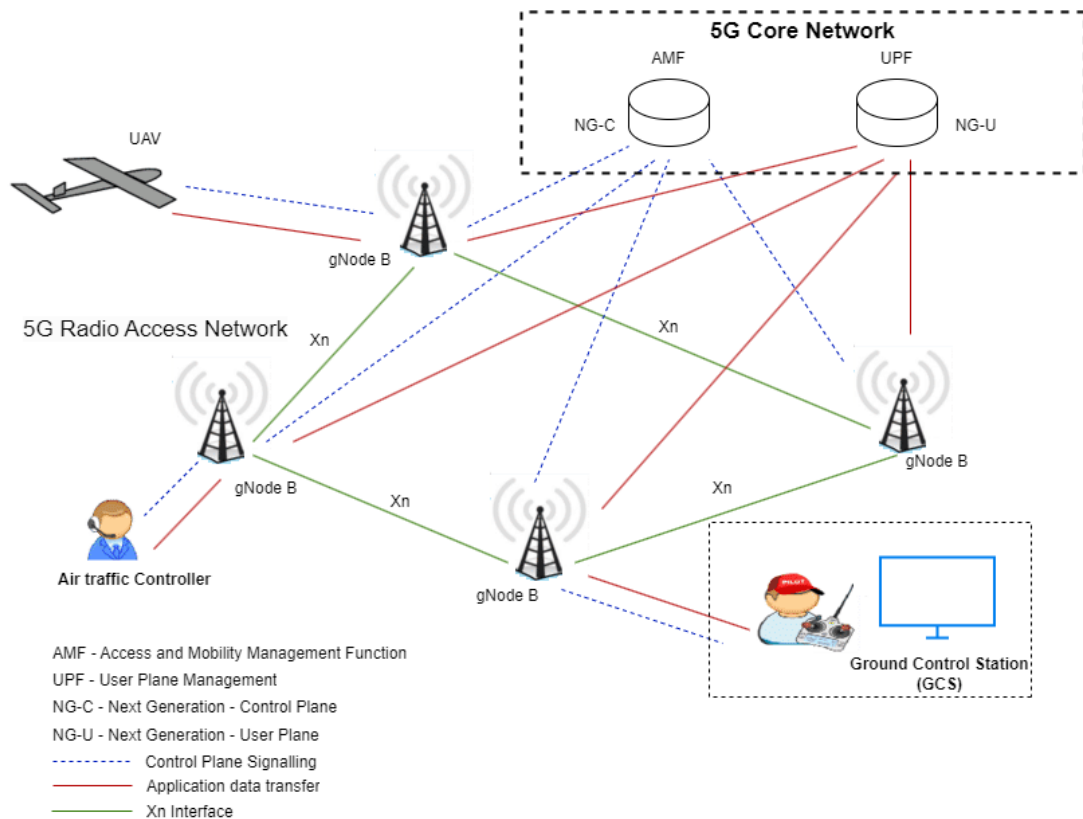


Figure 2: Standalone 5G RAN architecture for a UAV

The gNodeB establishes a connection to the Access and Mobility Management Function (AMF) for control plane signalling within the 5G Core Network. Additionally, the gNodeB links with a User Plane Function (UPF) to facilitate the transfer of application data. The interconnectivity among multiple gNodeBs is achieved through the Xn interface.

Several studies have explored this concept of leveraging 5G technology, some focus on 5G-connected drones which can improve emergency situations. Drones with high-quality cameras and 5G transmission can quickly survey disaster areas or hard-to-reach infrastructure, sending real-time footage to assess damage and guide responders [14]. A similar solution has been implemented where violence is detected using drone surveillance system [15]. A deep learning model that gives high accuracy, fast processing speeds, and has a small memory footprint for real-time deployment was developed. This solution will benefit from a 5G network which offers a greater bandwidth and low latency.

4. Objectives

This research aims to showcase the extensive capabilities of the 5G Radio Access Network (RAN) to support the increasing need for video surveillance security and policing. The paper seeks to illustrate how the integration of 5G technology with drones can significantly contribute to crime reduction. The contributions are as follows:

- We aim to propose how a surveillance UAV can effectively aid law enforcement in terms of deterring crime, responding promptly to crime incidents, and providing valuable evidence for prosecution purposes. The presence of UAVs patrolling the sky will likely deter crime more effectively than stationary cameras with blind spots. The uncertainty of being observed and the unpredictable angles from which surveillance may occur significantly enhance the deterrent effect on criminals. There is a time lag between the occurrence of a crime and when it is reported. Therefore, live streaming surveillance will allow law enforcement to respond faster. They will be able to see a crime incident as it unfolds. The video surveillance footage can also be used in a court

of law as evidence to ensure that the perpetrators are punished. This paper will give details of what can be done to enforce the law.

- Our intention is to demonstrate how to maintain a stable connection between a UAV and a 5G RAN. The communication between the UAV and the base station serves primarily three purposes: remote control, data transmission, and video transmission.
- We also propose deployment strategies aimed at ensuring both cost-effectiveness and operational efficiency. Assigning a UAV to each crime hotspot is impractical and financially burdensome due to the numerous locations that require video coverage. Deployment strategies will ensure that resources are shared, and operational costs are minimised while achieving greater results.

5. Methodology

The proposed methodology for UAV deployment and flight path is designed to be adaptable to any metropolitan city in South Africa. However, the unique characteristics of each city introduce specific challenges. For instance, in the City of Tshwane, compliance with the UAV flight regulations enforced by the South African Civil Aviation Authority (SACAA) becomes paramount [16]. One notable restriction is the prohibition of UAVs within a 10km radius of an aerodrome, which applies to Air Force base and Wonderboom Airport. This flight regulation is consistent across South Africa. Therefore, the methodology must account for and navigate such city-specific challenges to ensure compliance with regulatory frameworks during UAV operations.

For surveillance, UAVs will record videos in public areas without obtaining the consent of individuals. The Protection of Personal Information Act (POPIA) enacted on July 1, 2021, includes provisions allowing the processing of personal information without consent under specific exceptions. Nonetheless, such processing requires a valid and legitimate purpose, accompanied by the implementation of robust measures to safeguard the collected data, and prevent unauthorised access [8]. South Africa's Constitution and common law, specifically Section 14 of 1996, safeguard the right to privacy. However, there is a lack of explicit guidelines on how to effectively balance the essential rights to privacy with the imperatives of public safety and security [8]. Privacy in public spaces remains a luxury we forfeit for our safety.

5.1 UAV deployment

Drone deployment will heavily rely on predictive policing. Predictive policing is a strategy that uses data and analytics to prevent crime. The probability of future offences at certain locations is determined using data of previously occurred incidences. This will be done to share surveillance resources among different geographical areas. Analysis of time and space predictive methodology will be used. This is a method that has been tried and tested [17]. It uses various statistical methods to identify areas with high levels of crime. Supervised machine learning (ML) algorithms will be used in forecasting. The intention is to detect areas where crime is likely to occur based on where the crime has occurred in the past. The proposed predictive policing process is shown in Figure 3. To use the ML approach, the input data will be divided into two - the training data and the test data. Once the model has been trained, it will be deployed, and new unseen data will be fed to the model to predict areas where crime is prone to happen. The unseen real-time data features that will be fed to the model are date, time, temperature, and precipitation.

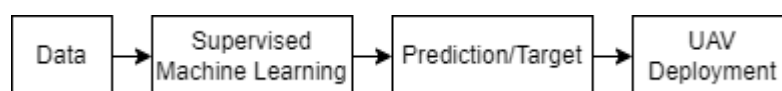


Figure 3: Predictive policing process

The area for deployment of UAVs will depend on the outcome of the model. The target will be the times, GPS coordinates, and wards of the metropolitan city. The UAV will subsequently be deployed to the specified area, considering the possibility of criminal activity during that timeframe. To enhance energy efficiency, it is essential to establish an ideal flight route based on coverage requirements and prevailing wind directions. Police stations will serve as docking points, facilitating battery charging or replacement for UAVs.

5.2 Data collection

Data will play a major role in creating a surveillance strategy. The available data might not have all the features needed to carry out this mission. The quality of the machine learning algorithm prediction depends on the quality of the training data. Therefore, it is important to ensure that the training data is accurate, and this can be done by validating the data while it is being captured. A data capturing system can be designed to minimise manual data entry by incorporating elements such as checkboxes and drop-down lists. This approach reduces the likelihood of errors. The input data will include the offence, geographical area, date, time, temperature, precipitation, and GPS coordinates.

5.3 Media transfer

The UAV will be paired with a high-resolution camera to capture surveillance videos. The aim is to access these videos on the ground station in real time. 5G technology offers a higher bandwidth, allowing faster and smoother transfer of video data and a better live broadcast. The 5G broadcast does not require a dedicated spectrum allocation, any spectrum can be utilised, from the low to the higher bands. The 5G technology can use more frequencies across the low band, which is less than 1GHz, the medium band, which is between 1GHz and 6GHz, and the higher band which is greater than 24GHz. Lower frequencies will have low speed but greater coverage, and higher frequencies will have high speed but low coverage. However, 5G networks have the flexibility of switching frequencies in long-distance communication and short-distance communication. Therefore, a UAV transmitting data over the 5G network will more flexibility. Multiple frequencies can be used simultaneously to achieve the best performance. The UAV can use low band frequencies when it is at high altitudes and far from the base station, and switch to high frequencies when it is closer to the base station at low altitudes. Signal dead zones at high altitudes will be mitigated by the frequency adjustments.

5.4 UAV Control

The deployment of the UAV in a metropolitan city will require high precision control of the UAV due to the complex terrains of the city at low altitudes. A stable and reliable connection is necessary. The end-to-end communication delay is lower on 5G networks. 5G offers an extremely low latency of **1ms** which will allow the UAV to be controlled from the ground station, anywhere within the network with minimal delay. The response time on a 5G network is **1ms** or less which is good for remote control of the UAV in complex terrains. A configurable, virtual, and dynamic RAN of 5G allows the network to perform at a high throughput and extremely low latency.

6. Proof of Concept (PoC) Validation

To validate the proposed solution, a UAV prototype can be developed to test its functionality on a RAN. The key features of 5G that are important to this use case includes high data rates, low latency, and massive connectivity of devices. The high data rates will allow the UAV to transmit large data in real-time, and a low latency will minimise the communication delay between the ground control station and the UAV. The 5G network can also allow for many UAVs to be connected. Therefore, there is no restriction on the

number of UAVs that can be deployed. These features can be tested using an open 5G network.

The Council for Scientific and Industrial Research (CSIR) has effectively implemented a 5G testbed, employing various combinations of RAN and core network stacks, such as OpenAirInterface, srsRAN, UERANSIM, Open5GS, free5GC, Cumucore, and 5G Core(5GC). To present our proposed UAV solution, we specifically selected the test bed using the srsRAN (constituting baseband unit and SDR) and open5GS (constituting the core network) platforms for demonstration purposes [18]. The UAV connects to the network as a User Equipment (UE) as shown in Figure 4. The figure provides a visual representation of the interconnections between the components of the 5G testbed, the internal connections within the UAV, and the interface between the UAV and the 5G testbed.

The selection of the hybrid-VTOL design is based on its amalgamation of advantages from both fixed-wing and multirotor configurations, rendering it the optimal choice for video surveillance. The fixed wing ensures efficient forward flight, significantly reducing power consumption and extending flight durations. Hybrid designs boast an increased payload capacity compared to multirotor designs, facilitating the carriage of additional equipment like cameras and sensors. The adaptability of the hybrid-VTOL, due to its vertical take-off and landing capability, enables operations in confined spaces and challenging terrains, making it well suited for urban environments and surveillance missions.

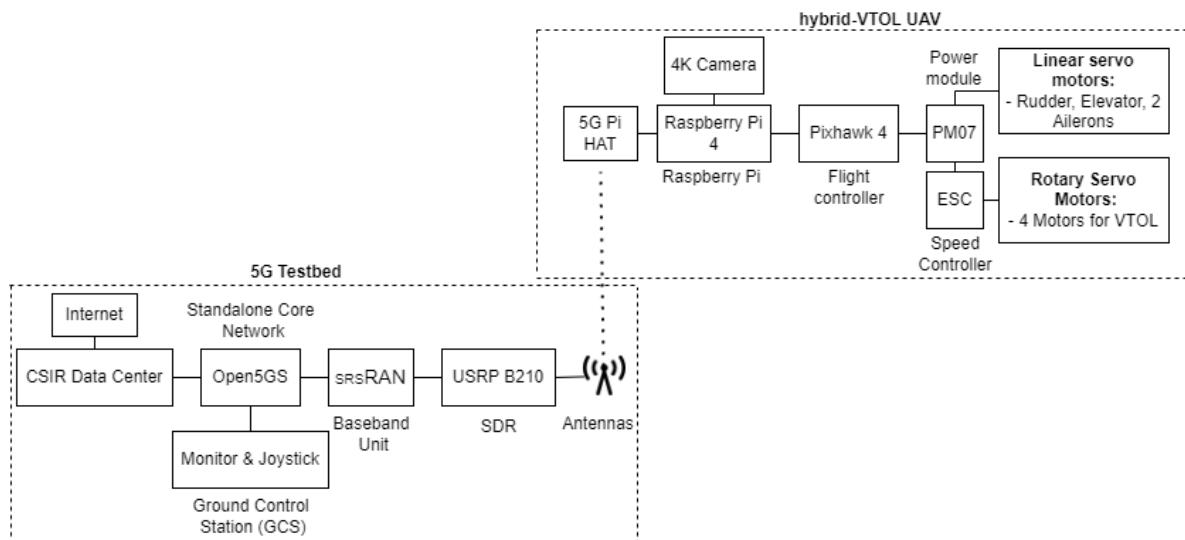


Figure 4: Testbed architecture

The components of the UAV and the 5G network are as follows:

- **5G Pi HAT:** The 5G Pi HAT module is used as the gateway to the UAV. The flight control instructions data from the cellular network are sent to the flight controller through the 5G Pi HAT.
- **4K Camera:** The camera is used to collect video data. It is connected directly to the onboard computer.
- **Raspberry Pi:** A Raspberry Pi is used as an onboard computer which interface a 5G Pi Hat to the flight controller. It also receives video data from the camera.
- **Flight controller:** The flight controller is the brain of the UAV. A Pixhawk 4 can be used for this application. This electronic device host software with different algorithms that control the flight of the UAV. It processes different signals from sensors and control commands and send signals to the electric motors.

- **Power module:** This module serves as the power management board, and it provides a regulated power to the motors. It also acts as a gateway between the flight controller and the servo motors.
- **Speed controller:** The electronic speed controller is used on the rotary servo motors to regulate speed.
- **Servo motors:** There are two types of servo motors on the hybrid-VTOL, the rotary and linear motors. The linear motors control the ailerons, rudder, and elevator. The rotary motors drive the propellers which are responsible for a vertical take-off of the UAV.
- **Software Defined Radio (SDR):** This radio communication system relies on software for the modulation and demodulation of signals [19]. It performs signal processing of the RF signals received by the antennas.
- **Baseband unit:** The srsRAN is used as a baseband unit. It is CU and DU software solution. It simplifies the open RAN deployment, supports the USRP radio, and integrates with the open5GS core network.
- **Standalone core network:** The Open5GS is used as a standalone core network of the 5G testbed.
- **Ground control station:** The ground control station comprises of control and monitoring equipment, such as the joystick and the monitor. This is where remote instructions are executed.

A bidirectional communication link should be established between the UAV and the testbed. Sensor data from the UAV will be transmitted to the testbed, providing confirmation that the executed command has been successfully carried out. The testbed will transmit UAV control commands, which the UAV avionic system will convert into avionic functions. These functions will control flight surfaces, including rudders, spoilers, and stabilisers. The testbed should receive the high-resolution video captured by the UAV.

7. UAV Testing

Testing the latency and video transmission quality are crucial metrics that need evaluation. The video quality over 5G network is dependent on several factors which include Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Reference Signal Strength Indicator (RSSI), and Packet Loss [20]. RSRP is the power of the reference signal received from the testbed. It will be used for estimating the power of the data-carrying signals coming from the testbed. RSRQ is the quality of the reference signal received from the testbed. It is the ratio between the power of the reference signal and the remainder of the signals within the current 5G band. RSSI is the total power received by the resource element. A resource element typically refers to the basic unit of resource allocation in wireless communication systems, especially in the context of Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a modulation technique widely used in modern communication standards such as 5G. Packet loss serves as a fundamental measure of the quality of a data communication link. The rate at which data is transmitted over the network (throughput) will also be assessed from the UAV's onboard computer (Raspberry Pi). It involves determining the speed and efficiency of data transfer, and this is important in understanding the testbed's performance and capacity for transmitting data. Latency will be quantified by analysing the time lapse between input commands and the ensuing actions throughout UAV operations. This evaluation involves implementing data logging on the UAV's control system, with the collected data then scrutinised to determine the latency in the execution of control commands.

8. Socio-Economic Benefits

A surveillance UAV provides several business benefits such as reduced crime, cost saving, quick response, improved investigations, lower insurance premiums, and improved public safety. Crime will be deterred by UAV patrolling. It has been proven in the above-mentioned literature that the presence of police deters crime. The government (especially law enforcement/police force) will benefit financially because their expenditure will be reduced when resource allocation is optimised. Resources will be strategically deployed in areas where they are needed. This will be assisted by the predictive policing strategy. The predictive policing will help the police to respond to crime incidents quickly. The surveillance UAV will further support law enforcement in conducting investigations by providing timely high-resolution video-based surveillance evidence. Finally, the public will enjoy the advantage of residing in a secure environment, leading to lower insurance premiums. This is attributed to the fact that insurance rates are determined based on the level of risk.

9. Conclusions

In this paper, we revised various crimes impacting South Africa and explored the mitigations that have been implemented and their limitations. Based on analysis, a solution involving UAV-based video surveillance was proposed. The proposed solution is currently a work in progress, with limitations such as the dependence on obtaining sufficient data to create predictive models for UAV deployment. The prototype will undergo development and subsequent testing on a 5G testbed developed by the CSIR. The Quality of Service (QoS) of the testbed will be assessed using a UAV paired with a 4K camera as user equipment (UE). The UAV functionalities will also undergo testing using the testbed in the capacity of a ground control station (GCS). Metrics such as RSRP, RSRQ, RSSI, packet loss, throughput, and control latency will be employed to assess the effectiveness of the solution. This particular 5G use case is worth pursuing due to its substantial benefits that can have a significant positive impact on society.

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