Implementation of Cellular-Based Drone Module using Cloud Services

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***Abstract*—The notion of a smart city incorporates the integration *of* infrastructure, services, and the community and encompasses the deployment of unmanned aerial vehicles (UAVs) for monitoring crop fields, facilitating logistics delivery, and performing high-altitude cleaning tasks. In a smart city, the interconnectedness of devices is realized through the medium of the Internet of Things (IoT). This research endeavors to explore the usage of Beyond Visual Line of Sight (BVLOS) for enabling remote command and control of UAV/UGV modes, leveraging 4G/LTE connectivity as an enabler. 4G/LTE connectivity is known for its improvement in data transfer speed and network capacity, which potentially enables the connection of more devices, including drones. The high availability and scalability of cloud services have become crucial factors in utilizing cloud services as the most cost-effective and expedient relay for connecting two nodes over the internet globally for now. The proposed methodology would be integrated into a smart drone module, which would be deployed at a small scale as a component of the Intelligent Transportation System (ITS).**

Keywords—BVLOS, Cloud Services, Internet of Things (IoT), Unmanned Vehicle

I. INTRODUCTION

The smart city model is predicated on the integration of its constituent components, including services, society, infrastructure, energy, and the economy [1]. The implementation of smart cities has already commenced, with some initiatives beginning with the integration of intelligent shopping and smart homes [2]. One of the most intriguing smart city concepts involves the use of drones. Often depicted in the film, drones can operate autonomously to perform a myriad of tasks, ranging from crop monitoring and package delivery to cleaning skyscrapers [3-5]. Given the rapid advancements in drone technology, innovative approaches are essential to improve performance and promote continued progress in this field.

The smart city paradigm facilitates interconnectivity between a diverse array of objects via a range of internet protocols, collectively referred to as the Internet of Things (IoT) [6]. To date, drones and unmanned vehicles have been confined by the range of the remote controllers, which is governed by the transmission frequency and signal strength. Consequently, the development of an advanced communication protocol capable of surpassing these limitations is imperative. Fortunately, a majority of regions in Indonesia have access to the 4G LTE network, thereby creating the possibility of creating a remote control communication protocol that operates via the internet [7].

The research topic of 4G UAV/UGV Enabled has been posited as a response to the growth of the Internet of Things (IoT) landscape [8]. This development presents additional prospects regarding the command and control mechanisms of unmanned vehicles. With 4G connectivity, the operator of the unmanned vehicle can exercise control without being constrained by the physical distance between the controller and the vehicle, provided that both parties remain connected to the 4G internet network [9]. The control methodology employed is BVLOS (Beyond Visual Line of Sight), which implies that the pilot/controller and vehicle observers lack direct visual contact.

Incorporating vehicle data into an internet-based database presents the potential for innovation by facilitating integration with other objects [10]. This feature permits inter-vehicle communication, enabling each vehicle to discern the trajectory and position of other vehicles, thereby reducing the risk of accidents and improving operational efficiency [11]. This development can enable a single vehicle to execute multiple tasks simultaneously by optimizing the algorithm governing its operation.

The objective of this research is to deploy a small-scale implementation aimed at enhancing the Intelligent Transportation System (ITS). A quadcopter drone is utilized as a proxy for unmanned aerial vehicles, while ground-based unmanned vehicles (UGV) are also subjected to the research. Thus, a Rover is employed to simulate future vehicles, including electric buses with integrated intelligence algorithms for parcel delivery.

To support our research, we utilized the Ardupilot software suite, which provides various tools for displaying land and air vehicle data via MAVlink communication. The test vehicle's central processing unit was based on the ARM architecture and utilized the Pixhawk device, which incorporates sensors like a gyrometer, barometer, and compass. We can also add other sensor modules that support UART, IIC, CAN, or SPI communication protocols. Finally, the Pixhawk was programmed with Copter or Rover firmware to support our research.

II. Methods

A. BVLOS

BVLOS, or Beyond Visual Line of Sight, is a method used to control unmanned aerial vehicles (UAVs) or unmanned ground vehicles (UGVs) from a remote location where the vehicle is not visible to the operator [12]. The BVLOS method requires an advanced communication protocol to control the vehicle as the distance between the operator and the vehicle exceeds the limit of the control range set by the vehicle controller [13].

The BVLOS method typically involves using an internet-connected device to control the UAV or UGV through a software suite such as Ardupilot or Mission Planner, which displays vehicle data for both land and air through MAVlink communication [14]. The vehicle's control device is typically based on the ARM architecture and includes sensors such as a gyrometer, barometer, and compass.

To implement BVLOS, the vehicle is installed with a Pixhawk device and firmware such as Copter or Rover [15]. Additional sensor modules can be added if they support the UART, IIC, CAN, or SPI communication protocols. With BVLOS, the operator can control the vehicle without being physically present, opening up possibilities for applications such as package delivery, surveillance, and search and rescue operations [16].

B. System Design

Fig. 1 below represents the communication architecture between the drone and the Ground Control Station. This architecture uses cloud service to enable communication for transferring MAVlink communication. The downlink communication starts with sensors and actuators that provide data for the flight controller. Using UART communication, the MAVlink stream will be forwarded to Nvidia Jetson Nano. Then Nvidia Jetson Nano will start an automation code to initialize routing the MAVlink stream to the regional server using reverse SSH. Lastly, the Ground Control Station will receive the MAVlink packet using local port forwarding through the Virtual Private Server. The uplink communications are similar to the downlink communication.

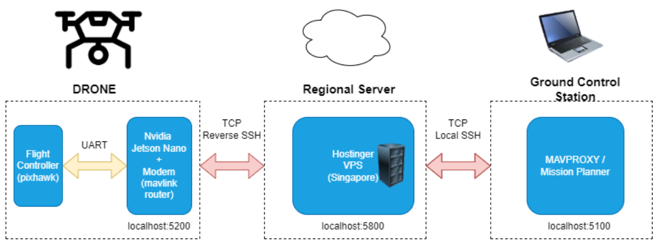

Fig. 1. Network System Architecture

C. Hardware Components

Nvidia Jetson Nano is a single-board computer capable of entry-level edge AI applications. We use this module to transfer the MAVlink packet over the internet for prototyping. This board runs software to manage the networking side of telemetry. For further work, the Nvidia Jetson Nano, as it was meant for AI, this board could be used to build a smart drone by implementing AI works.

Xidol K5188 is a cheap 4G internet module to enable 4G communication for transferring MAVlink packets [17]. This module supports various 4G bands, making it very flexible. This module hosts 2.4GHz Wi-Fi to Nvidia Jetson Nano and other devices. Using this connection, our GCS can SSH through the Nvidia Jetson Nano to monitor or configure the connection as long as they're in close range.

Pixhawk 2.4.8 is a flight controller that controls drone movement and is capable of autonomous flight. This module combines a bunch of sensors and actuators to navigate. Pixhawk is largely used around the world as it's open-source hardware to develop the autonomous system.

The drone will carry all hardware components and also have to provide a minimum power delivery for each component. XL4005 provides a minimum 5V/2A to power the Nvidia Jetson Nano and the Xidol K5188. Fig 2. below shows the process for power delivery.

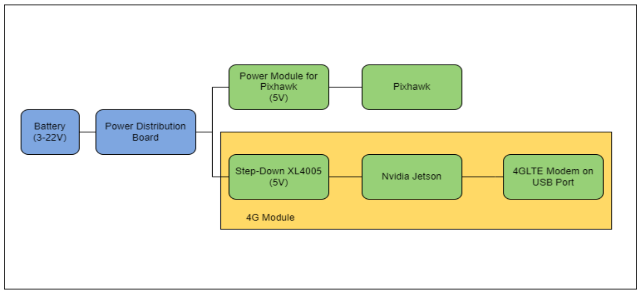

Fig. 2. Hardware power delivery

D. Software Components

Pixhawk 2.4.8, as our hardware flight controller, used Ardupilot firmware (AC 3.6.9) to do flight-controlling tasks and send MAVlink packets. Ardupilot is an open-source firmware that is commonly used in various flight controllers, making it very versatile. Ardupilot features fully autonomous flight and is developed by a large community of professionals and enthusiasts. We can also use other firmware, such as PX4, that QGroundControl supports to transmit MAVlink packets to the ground control station.

As our MAVlink node, the Nvidia Jetson Nano used Ubuntu 18.04.6 LTS based on Jetpack 4.6. Ubuntu is used as this OS runs on default Nvidia Jetpack 4.6 firmware. Any module can be used as long as it has compatibility with the Jetson Nano kernel. Ubuntu is largely used on Linux-based systems, making it very easy to use.

MAVlink-router is software that routes MAVlink packets through various devices via TCP, UART, or UDP protocol. MAVlink stream from the flight controller will be passed into Nvidia Jetson Nano via UART communication protocol. From there, Nvidia Jetson Nano will build the connection for transmitting MAVlink packets using public IP and port.

MAVproxy is a command-line-based ground station software made to be minimalist and portable to support MAVlink protocol. Thus, this software has several key features. For example, it can forward MAVlink packets from its device to some ground control station endpoints with a different protocol (UDP/TCP). This module is easy to install and implement. A developer can install it through the python module manager (pip) and deploy it on the terminal.

Crontab is an automation software containing instructions to run in a daemon at a specific time. After every booting time, this software automation can be done by running a bash script in the crontab configuration file. This bash script will build an SSH tunneling for reverse port forwarding from Nvidia Jetson Nano to cloud services. Thus, with crontab, every time the connection between the Cloud and Nvidia Jetson Nano breaks, it will automatically rebuild a connection by checking the reverse port forwarding process ID.

E. Network Stacks

WI-FI provides 4G connectivity to Nvidia Jetson Nano to build a connection to the cloud. The 4G internet connection is accessible through XIDOL K5188 WI-FI using Telkomsel internet service provider. XIDOL K5188 will directly connect to the Nvidia Jetson Nano through USB ports on the Jetson Nano. From then, WI-FI receiver-Tp Link TL-WN725N V3-Nvidia Jetson Nano will connect to the Xidol K5188 network. This configuration chosen as this configuration will make it easier to SSH to the Nvidia Jetson Nano terminal for debugging and troubleshooting.

A virtual Private Server is a node-link between the drones carrying the Nvidia Jetson Nano and the Ground Control Station. Virtual Private Server was placed in Singapore to provide a low-latency connection between the drone and GCS. Virtual Private Server will provide a public IP for reverse port forwarding script on Nvidia Jetson Nano so that the MAVlink stream from Nvidia Jetson Nano will be transmitted through the internet at the selected port. When the connection has been built, the MAVlink stream is accessible at localhost at the Virtual Private Server.

F. Automation Setup

Automation is mandatory to make this module easier for everyone and to rebuild a connection if the connection is reset. Fig below shows how the automation script on Nvidia Jetson Nano works. Notice that every connection that has been built will automatically create its process ID. So, every time the connection breaks, we can delete the process ID and rerun the reverse port forwarding script.

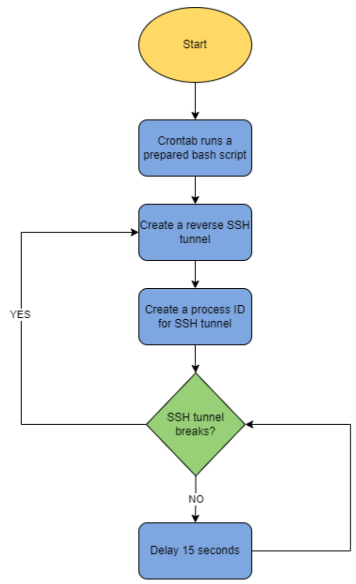

Fig. 3. Automation code on Jetson Nano

III. Result and Discussion

There are two main aspects that this research focuses on regarding the implementation. The first aspect about the connectivity reliability, as this is a 4G telemetry module, should be able to perform a stable MAVlink-packet communication between the drone and GCS(s). The second aspect is automation setup, which means this study aims to build an automation script for a connection using bash scripts.

The specification for this study used a Telkomsel Cellular Network and Windows Ground Control Station. Testing was held outdoors in Bandung with decent 4G internet connectivity. Virtual Private Server located in Singapore with 99.9% uptime, which means it will be rare for the server to go down. An automated bash script on crontab will automatically build a connection whenever the server goes down.

A. 4G Telemetry Module

Fig. 4 Shows the 4G telemetry module hardware setup. Notice that this module used step-down converter XL4005 to provide a stable power consumption. Stable 5V/2A power was successfully delivered to power on the module during the test. This power delivery setup was chosen as the drone commonly used a Li-Po battery to power the drone.

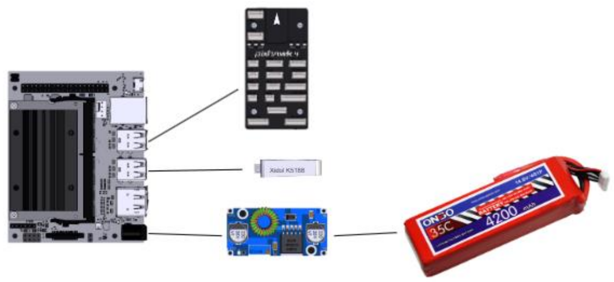

Fig. 4. Module Schematic

B. Automation Setup

A bash script placed on the crontab configuration file will be executed every time the Jetson Nano reboots. The bash script will keep looping every 15 seconds to check the SSH tunnel connection. Table I below shows the difference between the manual and automated steps. Notice that the manual steps require much work to set up. For the inexperienced user, these steps take much work to do. To overcome this, bash script is implemented both on GCS and Jetson Nano.

TABLE I. Proposed Automation Script

Node	Manual	Proposed Auto
Jetson Nano	• Granting access to Pixhawk USBport • Generating MAVlink-stream using MAVlink-router • Building a reverse SSH tunnel • Matching RSA key or using a password to build an SSH tunnel	Bash script (airModule.sh)
GCS	• Building a local port forwarding to Virtual Private Server • Matching RSA key or using a password to build an SSH tunnel	Bash script (GCS.sh)

When building an SSH tunnel, a password is required for authentication. This method is relatively complex for automation when the connection breaks. Otherwise, matching the RSA key on both node configuration SSH files will fix this problem. By doing so, whenever the connection breaks, the SSH will not ask for authentication (using a password), as both nodes already know the known host and its RSA public key. Our proposed automation script will automatically reconnect the SSH tunnel every 15 seconds using the bash script on a crontab that runs in the background.

C. Testing

MAVproxy, as a Ground Control Station application, is used to determine network quality using TCP protocol. MAVproxy will count the packets received and lost during transmission between nodes. We're testing three different configurations. All test conditions use a modem as the main internet gateway for the Jetson Nano. But the difference is that the first two tests use mobile phone hotspots as the internet gateway for the GCS. This simulates the outdoor scenario.

Meanwhile, the third uses a proper internet connection like a home-WI-FI connection to simulate the indoor scenario for GCS. The devices will send and receive MAVlink packets for 5 minutes straight. Table II below shows that there's no huge difference between these three configurations. Only the difference is the delay due to the mobile hotspot network infrastructure.

TABLE II. 4G TELEMETRY TESTING

No	Packet(s)	Lost	Rate	Delay
1	26064	116	99.6%	45ms
2	23967	70	99.7%	48ms
3	25358	0	100%	20ms

The latest research has found that CloudStation, a web service for Ground Control Station, offers drone-user connectivity by accessing cloud services' public IP. However, this method requires high computing power as it has to run a Database Management System (DMS), authentication, and a web server with low performance. It is unsafe and lacks features for flight control. In our proposed method, we use cloud services as a relay for Mavlink packets with low computing power. Mavlink packets will be processed by users directly using GUIs such as Mission Planner, QGround, and Mavproxy, maximizing their full features.

IV. CONCLUSION

The need for smart drones has been increasing to leverage human life. Some work has been done to connect drones to servers to support that. Eventually, all drones will be connected to the server to do specific tasks, so every drone has to support reliable communication connections. This paper focuses on building a minimum system to send and receive MAVlink packets over 4G internet. Based on testing, it's worth mentioning that it is possible to create a stable connection between portable GCS and Drones to control or stream data as long as both nodes are connected to the internet.

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