Drone Operations and Communications in an Urban Environment

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Abstract—The last few years have seen a growing interest in Remote piloted aircraft systems (RPAS), also known as Unmanned Aerial vehicles (UAV) or drones. Domains of application The Unmanned Traffic Management (UTM), adopted in Europe as U-Space by the Warsaw Declaration, have triggered numerous research and development projects on securing drones flights in an urban area. The EU project USEPE funded by the Single European Sky ATM Research Joint Undertaking (SESAR) focuses on ensuring a safe separation of flying drones in an urban setting. There are many technical and societal challenges to tackle to ensure that drones are safely and securely integrated into European airspace (U-space). For instance, real time communication between millions of drones and Air Traffic Control (ATC) rises concerns for the implementation, especially dense aerial activities in urban areas. Therefore, the implementation of highly populated drone systems requires a reliable communication network to maintain a real time information exchange. This paper investigates a model of reliable communication of multiple drones with the web-based ATC. Based on simulations of different use cases of multiple drones flying in an urban setting, we demonstrated that the Message Queuing Telemetry Transport (MQTT) is a promising protocol for the communication of multiple drones within a network. In our simulations, four drones communicated over a single network with the limited hardware namely RaspberryPi combined with the ThingsBoard.

Keywords-Drones; network; communication; IoT; MQTT; RaspberryPi

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have been around before they become popular. UAVs trace their modern origin back to the development of aerial torpedoes almost 95 years ago [1]. The UAVs were first designed for surveillance by the USA military. Nowadays, a drone can be equipped with any kind of sensors, therefore drone systems flying at low altitudes open up for a different kind of domain application such as delivery [2], photography [3-5], agriculture [6, 7], disaster management [8]. The shift in initial focus of surveillance can be traced back to advancements in other sectors, including battery technologies, improvement in motor power and size ratio, communication advancements, Global Navigation Satellite Systems (GNSS) for positioning accuracy and metallurgy, which help design low-weight chassis and improve other different factors affecting drone flight. Significant improvements in technology have greatly revolutionized different sectors of the market. Therefore, advances in drone technology initiated a chain reaction revolutionizing other sectors along with it.

Increasing air traffic density is leading to issues related to security and safety. To address these problems, the European Union has launched several initiatives and regulations under the "European Drones Regulation" for European airspace use [9]. Other countries like the USA and Japan have their UTM program as NASA UTM [10, 11] and Japan as JUTM [12]. By the end of 2016, The European Commission adopted the UTM concept in Europe and called it U-Space [10]. Since then, many research activities started at the European level, with funding of the European Commission through the Single European Sky Air Traffic Management Research Joint Undertaking (SESAR JU) [9].

Several EU projects focus on various technical challenges of separation or collision avoidance in order to ensure safe integration of drones in the European airspace. Our project, USEPE focuses on drone separation methods in

high demanding environments such as cities, by exploring the use of machine learning algorithms to automate the deconfliction of drones. They are many aspects to consider and one of them, for the simulation purpose, is the investigation of a suitable protocol of real time reliable communication between drones and eventually the air traffic management (ATM) systems. Several promising Internet of Things (IoT) communication protocols could provide reliable and scalable communications for drone to drone or drone to ATM. For example, "Bluetooth is a short-range, low-power IEEE open standard for implementing wireless personal area networks", but it cannot provide drone to ATM communication [13]. IEEE 802.15.4 committee started low data rate ZigBee technology and joined forces with ZigBee Alliance to further development [14]. A typical LoRaWAN network consists of end-devices commonly known as motes, gateways, and servers. Constrained Application Protocol (CoAP) was made a full Internet Engineering Task Force (IETF) Internet standard in 2014 officially [15]. "CoAP is a specialized web transfer protocol Analogous to Hyper-Text Transfer Protocol (HTTP) designed for use with constrained nodes and networks in the IoT (Internet of Things). The protocol design is extremely (Machine to Machine) M2M application-oriented to deliver low data packets [16]. Finally, MQTT is a lightweight publish subscribe messaging protocol designed and developed by Andy Stanford-Clark (IBM) and Arlen Nipper in 1999 for M2M [17].

The listed protocols are effective in their specified context. However, there are generic issues that should be considered in the implementation phase such as:

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1. Short Communication range
2. Communication Only within Visual Line of Sight (VLOS)
3. Large bandwidth requirement.
4. Higher power consumption
5. No data filter specification
6. Critical data security concern
7. Pairing and system compatibility

These advantages and disadvantages have been evaluated based on the drone's type, environment, and mission assigned to the UAVs. We considered two parameters such as flight dynamics and positioning for the selection of the proper IoT protocol. Preliminary investigations of available IoT protocols resulted that MQTT might be the most suitable one ensuring real time, reliable and scalable communications for a drone in an urban area. Section 2 outlines the adopted methodology and provides some implementation descriptions. The results of the experiments are discussed in Section 3.

II. METHODOLOGY AND IMPLEMENTATION

One of the aims of the USEPE project is to delineate a concept of the operation of drones flying in an urban environment. A basic concept of the operation of drones is depicted in Figure 1. Due to the structural environment such as buildings, we define a zone for flying as a corridor or highway to foresee that drones could move within specific corridors or highways and in respect of flying rules. A communication system could be easily integrated.

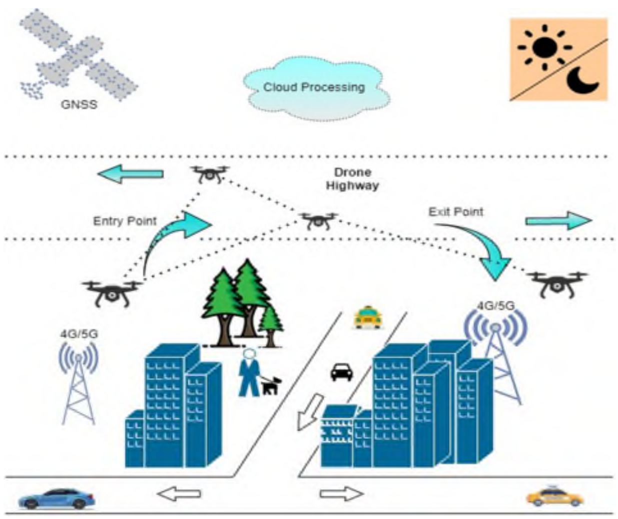


Figure 1. Concept of Operations of a drone mission.

A. MQTT Network Topology

MQTT is a lightweight publish/subscribe protocol designed around a central broker. Hence MQTT follows a simple start network topology, as shown in Figure 2. The broker acts as the centralized hub.

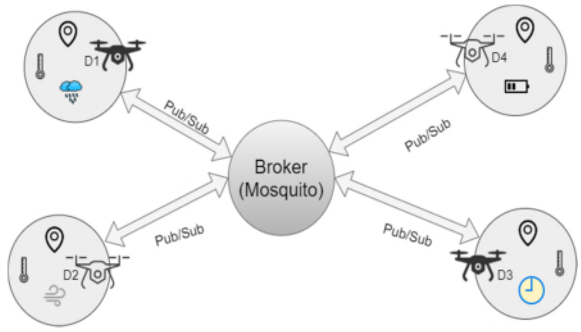


Figure 2. MQTT Star network topology.

The heart of implementing an Internet of Things (IoT) service is reliable network connectivity. Therefore, the 5G cellular network is used for reliable connectivity within urban airspace [18-21]. The generalized hardware structure is shown in Figure 3.

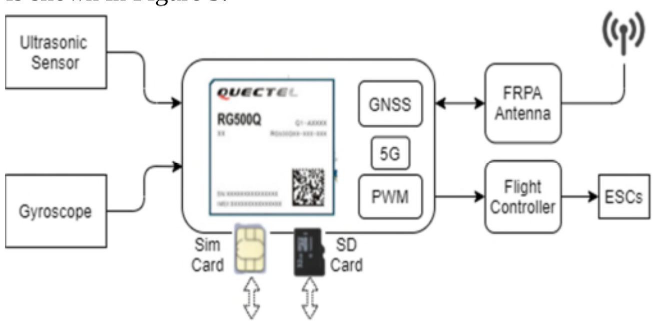


Figure 3. Interface Block Diagram.

1. Ultrasonic sensors

An ultrasonic sensor detects any nearby objects within the range. The scan distance depends on the specification of the sensor. Sensor-ranging detection capability from 1cm to 20m are commonly available types [22]. The sensor emits and detects a sonic pulse reflected by the object. HRLV-MaxSonar-EZ, an ultrasonic sensor product from MaxBotix with a range of 5m, is implemented in the practical. Any object within a range of 30 cm accounts for 30 cm. Since the sensor has a narrow beam angle of ~8°, the sensor is placed in the servo to scan 360°. The graphical representation is presented in Figure 4. The sonic pulse, time of flight between the emitter and the object, and back to the receiver is measured using the formula 1.

$$\text{Distance} = \frac{\text{Speed of sound} \times \text{Sonic time of flight}}{2} \quad (1)$$

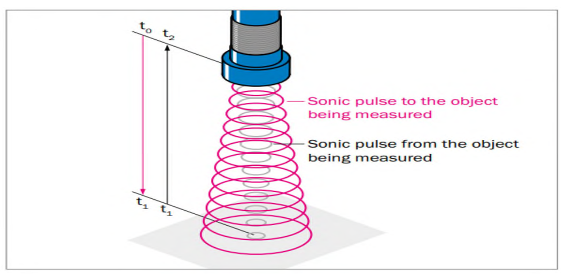


Figure 4. Time-of-flight measurement.

2. Gyroscope

A gyro sensor detects any angular tilt in the vertical and horizontal orientation of the drone. It generates an eventbased trigger each time the device angle changes (See Figure 5). Some advanced gyro sensors have a programmable average window and a programmable average threshold.

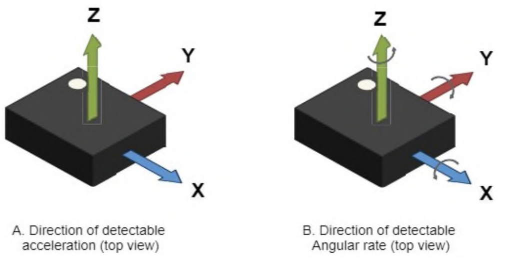


Figure 5. Lateral/Angular tilt Detection [23].

3. Raspberry Pi

The simulation of the drone communication is carried out using Raspberry pi 3b+. Features [24] of raspberry pi, 5V TTL logic level, Wi-Fi, GPIO's, and high processing power, make it ideal for simulation usage. Each raspberry pi is treated as a removed drone connected to the server. Sensors onboard to the raspberry pi continuously read the ambient data and continuously push the reading to the ThingsBoard. The data can be visualized in the ThingsBoard dashboard. The raspberry pi acts as a bridge linking the sensor data to the ThingsBoard. Therefore, it requires software that supports sensing the data from it to the server.

a) Paho MQTT

Paho is an Eclipse foundation project which helps to create an MQTT client. The client can both subscribe and publish data on any particular topic. Therefore, Paho MQTT client library is used for procuring the data to and from the ThingsBoard server.

4. ThingsBoard

"ThingsBoard [25] is an open-source IoT platform for data collection and processing, visualization, and device management". It enables connectivity via industry standard IoT protocols - MQTT, Constrained Application Protocol (CoAP), and HTTP facilitating both cloud and local deployments. ThingsBoard leverages device scalability, data visualization, cloud data processing, ensuring data protection. Features of ThingsBoard can be referred to [25].

B. Simulation Process

1. Take off approval

Only the authenticated drones must be allowed to fly and enter the flying corridors. Safety should be ensured by not only drone identification but also by monitoring how many drones are flying and where they are positioned. An approval system is therefore required.

Each drone connected to the ThingsBoard has a unique access token and device id. On creating a device, the access token and device id are autogenerated. Connection to ThingsBoard requires an access token, if not, the drone connection to ThingsBoard and the authentication will fail.

For any reason, like port number, incorrect URL, the compiler throws an error with error code 111. The error represents the socket connection error. The drone tries to reconnect to the server repeatedly with failed attempts until a valid access token is provided.

When the access token is authenticated, with connection session 0, the drone is granted permission to take off. The drone then follows the path instructed by the path planning algorithm. Static GPS coordinates are fed to the system in advance. The drone follows the static coordinates. The drones, on approved take-off, attain a vertical height of 250m which is considered default before any forward motion (See Figure 7). During the flight, all drones' states are monitored continuously as shown in Figure 6.

Drone

Drone name ↑	status	speed	battery
Drone 1	on route	89	100
Drone 2	arrived	0	100
Drone 3	climbing	40	20.0
Drone 4	decending	101.5	100

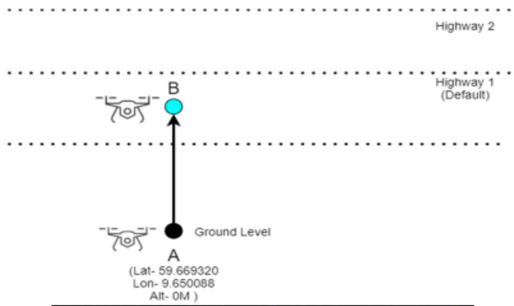
Figure 6. Drone Status.

2. Routing

The routing of a drone is divided into three different components.

a) Ascending

Once the drone is authenticated and approved for take-off, the drone firstly attains a default height of 250m, considering its initial position as the reference, as shown in Figure 7. Once the default height is attained, the drone makes any further moves.




```
Connection Established  {'session present': 0}
Authentication Successful
Clear for take-off
Current height = 0 M
Climbing to 250M altitude....
Current height = 1 M
Current height = 2 M
Current height = 4 M
Current height = 8 M
Current height = 16 M
Current height = 32 M
Current height = 64 M
Current height = 128 M
Altitude Attained = 250
```

Figure 7. Drone Ascending.

Position of the drone with changing time is shown in Figure 8 during the ascending phase of the flight.

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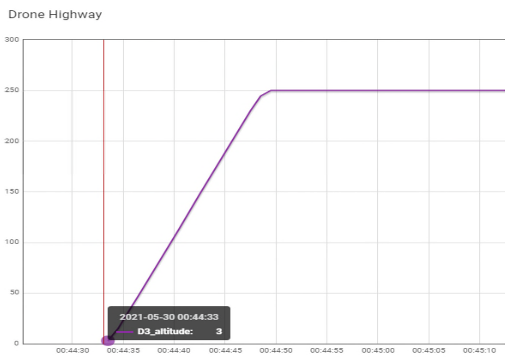

Figure 8. Drone Ascending Graph.

Once the take-off is clear, the current altitude of the drone is considered 0m. It is an assumed altitude; the initial height of the drone varies based on its area/region of operation. GPS sensor is read before in industrial practice. The drone slowly gains altitude with reference to its initial position coordinates. It follows initial reference coordinates until the drone attains the default height of 250 m. From 0m altitude to 250m, the whole process is considered as ascending of a drone.

b) On route

When the drone attains the default height of 250m, the drone then starts its forward journey towards its destination. The route from the end of ascending to the start of descending is defined as on route. In this stage, the drone makes an onward journey to the destination, continuously following the route as instructed by the routing algorithm. The GPS continuously reads the current position of the drone and continuously updates the server for any drift in position and correction of the same. Figure 9 represents the current drone status, drone 1 status as on route.

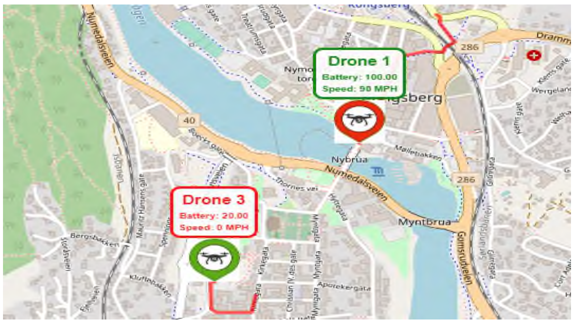

Figure 9. Drone on the route.

c) Descending

Descending is analogous to ascending, where the drone gradually climbs down the altitude from the current highway to the ground level. When the drone reaches its final GPS coordinate, the status of the drone is updated to "descending.". It then slowly climbs down, following the Euclidian path until it reaches ground level. In Figure 10, drone 1 represents the descending status of the drone. While the drone descends, the drone's speed is maintained to stop properly at the last 5m since its descending height for the safety of the drone and the payload it carries.

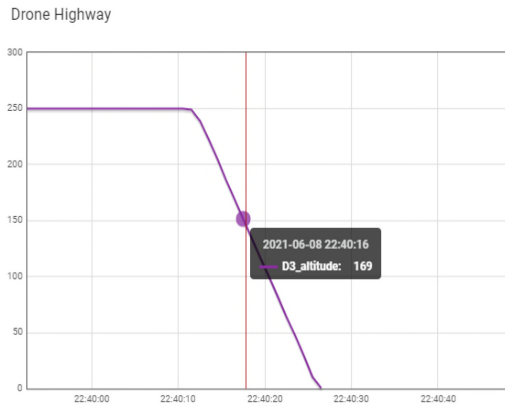

Figure 10. Altitude graph of landing drone.

3. Hovering

Hovering is a state where a drone maintains its current coordinates in the air, maintaining the same altitude. Hovering conditions, in general, can be programmed or autogenerated to prevent a collision. During the hovering state, the algorithm gets a chance to route/manage the traffic avoiding collisions or long flight time.

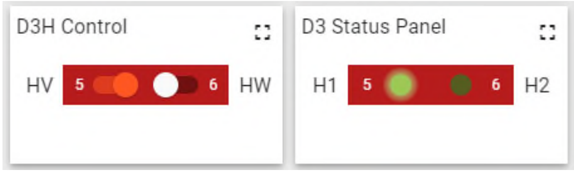

Figure 11. Hovering command and status panel.

Figure 11 shows that the hovering command is sent (HV), and the same is reflected as the drone's acknowledgment. This is the server-side command for hovering. However, an automated system is also incorporated into the project. The ultrasonic sensor onboard the drone senses the surrounding distance and objects' presence. If an object is closer than 5m, the drone updates its current status to hovering. When the other drone safely passes the shared route, the status of the hovering drone is changed back to "on the route," and the drone heads its further journey.

4. Object detection

HRLV-MaxSonar-EZ from MaxBotix is successfully implemented to detect any object in the drone trajectory. Two experimental cases were carried out in [26]. Figure 12 [26] is the trajectory of the drone. The blue line is the actual drone trajectory, while the line represents the ideal drone trajectory, and the red block is the object in the trajectory of the drone. The sensor continuously scans for any object in its vicinity.

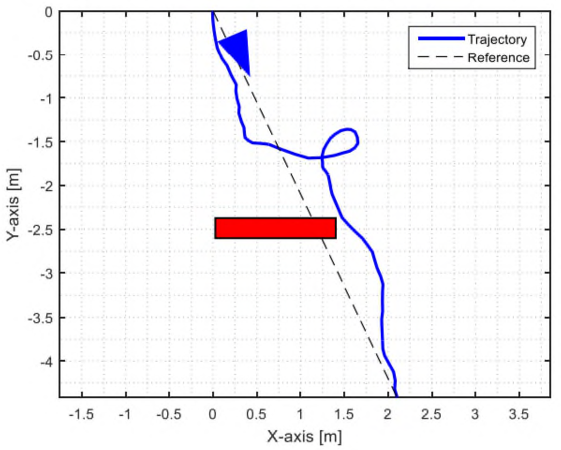

Figure 12. Drone trajectory [26].

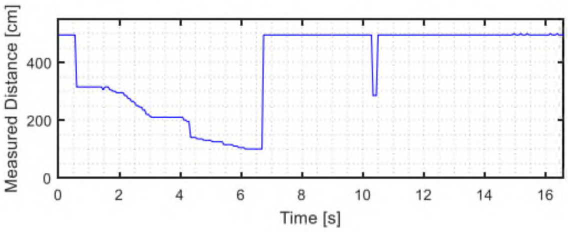

Figure 13. Distance vs Time [26].

Figure 13 [26] indicates that the drone reads the object in its trajectory and pushes itself back in ~6.4s. It then slightly changes its trajectory and avoids the object in its flight plan.

Therefore, real-time tracking of drones Beyond Visual Line of sight (BVLOS), enables dynamic routing, handle high traffic density. The monitoring and authentication of drones are efficiently completed.

III. Results and Discussion

Operating them beyond a certain meter to a few kilometers is a recurrent challenge that is addressed today by the concept of Beyond Visual Line of Sight (BVLOS) as opposite to VLOS flights, which are operated within the pilot's line of sight. In order to achieve the issue, real time communication and information exchange should be tackled since drones are controlled by on-board instruments. Information should be related for instance to the altitude position, speed, etc. In this paper, we describe an experiment based on MQTT protocol for multi UAVs' communication. MQTT provides a promising service in connecting multiple devices to a central hub.

Number of Devices: Theoretically, a single MQTT broker can handle millions of devices over a single network. As seen from the implementation results, on ThingsBoard, a web-based Internet of Things (IoT) platform efficiently handles four drones in a single network.

Data Delivery: A highly flexible data delivery and acknowledgment feature of MQTT proves to be very beneficial for different applications. Three MQTT QOS provides high flexibility, unlike any other protocol.

Visual Confirmation: A large number of widgets in the ThingsBoard provide visual confirmation. Therefore, ThingsBoard proves to be very user-friendly with an attractive dashboard.

Object Detection: Object detection by Ultrasonic limits to a short range with limited information of the type, structure, and property of their object detected.

The implementation of Multi UAV communication over the Internet of Things (IoT) using MQTT has been explored. MQTT uses a basic time-based routing algorithm to send data from a drone to the IoT platform. The conducted simulations served as one of the investigations to ensure a safe separation within the EU which is one of the objectives of the USEPE project. However, we have also identified some other challenges that need to be considered before integrating MQTT or adopting it in the framework of the flying drones platform simulator that is currently being developed by the project USEPE. Some of these challenges are listed below:

- Capacity management of the U-space will impact the communication models
- Minimal considerations regarding connection failure. A better security and emergency landing system, in case of connection failure, could highly improve the overall safety.
- An emergency delivery route needs a special focus based on priority requirement
- An optimum and efficient message routing algorithm using MQTT can optimize payload.
- Extrinsic factors like wind and atmospheric pressure are not considered in our experiment
- Exploring the use of LIDAR. Ultrasonic sensors can only detect the presence of an object that has a limited range of detection of ~20m, while LIDAR can sense other properties of objects such as shape, size and have a range of detection of 75–660m [27].

IV. Conclusion

Autonomous aerial vehicles are gaining high interest not only from the research community but also from the business community. Drone operations in an urban environment will become a reality, but several technical challenges should be tackled for ensuring a safe separation by preventing and eliminating risks of drone collision. The USEPE U-Space is exploring techniques to solve the crucial issue of separation management for a safe integration of drones in the urban space. However, issues such as investigating the best protocol for communication and information exchange should be investigated. This paper describes an experiment conducted on the use of the MQTT protocol for communications. The conducted simulation and the outlining results show that MQTT is a promising protocol for real time and scalable communication for drones that could be integrated with the USEPE simulation drone platform for ensuring a safe flight in urban areas.

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