A Simulation of a Real-Time Cloud-Based Communication Bluetooth Low Energy (BLE) System in Automatic Dependent Surveillance-Broadcast (ADS-B) for Unmanned Aerial Systems (UAS)

Morgan State University

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Summary Statement

A Simulation of a Real-Time Cloud-Based Communication Bluetooth Low Energy (BLE) System in Automatic Dependent Surveillance Broadcast (ADS-B) for Unmanned Aerial Systems (UAS)

The development of unmanned aerial systems (UAS) has evolved over recent years. The purpose of our project is to address the need for a scalable unmanned aerial systems (UAS) communication and collision avoidance system by providing a web application that can leverage the power of highly distributed, cloud-based communication bluetooth low energy systems. Cloud-based communication between UAS will mainly be used. Bluetooth low energy (BLE) systems will be utilized with the help of Automatic Dependent Surveillance Broadcast (ADS-B) if wireless systems are down. Three scenarios are analyzed to map the cloud-based BLE algorithm with Sense and Avoid (SAA) capabilities. These three scenarios are: drone-to-drone communication, drone-to-taxi communication, and taxi-to-taxi communication. The contributions of this work are to integrate the design of real-time flight monitoring, communication and visualization of multiple UAS, collision detection and avoidance with automatic adjustment of UAS flight paths, scalability support via cloud systems, implementation and performance simulation. A risk assessment is completed to identify potential risks of implementing the proposed protocol, as well as the level of risk and mitigation strategies. An analysis of costs and benefits is completed to assess the feasibility of the concept. The impact of this work can be applied to various fields: healthcare, transportation and logistics, infrastructure, economy, security, and the environment. More specifically, this technology can provide disaster relief resources, monitor critical infrastructure, deliver medical supplies to those in need, assist in accessing hard-to-reach places, increase jobs, and provide aerial surveillance capabilities.

Problem Statement and Background

The purpose of our project is to address the need for a scalable unmanned aerial systems (UAS) communication and collision avoidance system by providing a web application that can leverage the power of highly distributed, cloud-based communication bluetooth low energy systems. To properly address the problem statement, the UAS control system must provide:

1) A detailed, visually-driven graphic user interface that provides an interactive map interface and a detailed view of individual sensor data;
2) A scalable framework that can accommodate Sensors multiple concurrently connected UAV systems and with frequent sensor data updates;
3) A collision avoidance system that can send UAS flight commands and react quickly to potential collision situations; and
4) A well-designed framework that can be deployed, cleared and redeployed easily on cloud-based computing services.

For each connected unmanned aerial vehicle (UAV), detailed UAV sensor readings from the accelerometer, GPS sensor, ultrasonic sensor and visual position cameras will be provided along with status reports from the smaller internal components of UAVs (i.e., motor and battery). The dynamic map overlay visualizes active flight paths and current UAV locations, allowing inter-communication of all aircrafts easily. Our system will detect and prevent potential collisions by automatically adjusting UAV flight paths and then alerting users to the change. We develop our proposed system and demonstrate its feasibility and performances through simulation.

Automatic Dependent Surveillance Broadcast (ADS-B) shares an aircraft's altitude, position, velocity, and other parameters with air traffic controllers (ATC) and other aircraft. The ADS-B system includes ADS-B Out (transmit), ADS-B In (receive), and ADS-B Sense-and-Avoid (SAA). There are two types of ADS-B:

1. ADS-B that transmits data at 1090 MHz with 50 kHz of bandwidth. This is mainly used for global applications.
2. ADS-B that transmits data at 978 MHz with 1.3 MHz of bandwidth. This is mainly used for implementation within the United States and is also able to broadcast weather data.[1]

Project Description

Project Description, Section I

Concept

Though the concept of UAS is promising as an emerging technology, the field is relatively new to industry and is much less developed than other military applications. There are various issues to address in order to realize the effective, stable and reliable use of UAS, i.e., network topology, routing, seamless handover, energy efficiency and management. As the number of potential users of UAS increases, it is especially important to provide mobility management, control and monitoring including collision avoidance of intruders or obstacles. The use of unmanned aerial systems (UAS) has increased exponentially in recent years. The effective use of UAS for civilian or military applications requires flight through various civilian, restricted, and military airspace classes. Some UAV monitoring and control systems focus on wireless radio as the most crucial aspect of the control unit. In a centrally-designed system, the controller radio facilitates communication between every UAV in the system; without the controller radio, the system could not function. Air Traffic Control (ATC) is a service provided by ground based personnel, known controllers who direct aircraft and other vehicles in such a way to provide a safe, orderly and expeditious flow of traffic on the ground and in the air. ATC systems worldwide separate aircraft to prevent collisions, organize and expedite the flow of air traffic and provide information and other support for pilots when available. Also, to ensure that UAS do not disrupt other airspace users, they must be integrated into the current National Airspace System (NAS). Although the growth in the use of UAS in civil applications is relatively new, guidelines or requirements have already been developed to regulate the use of these vehicles in NAS. In likely future scenarios, with myriads of UAS offering different types of services and sharing the same airspace, it is not feasible to develop a centralized path planning strategy that ensures the absence of collisions between all these UAS. Therefore, a decentralized/coordinated collision avoidance strategy must be implemented, so that UAS can dynamically detect/resolve these situations.

In recent years, a system called ADS-B (Automatic Dependent Surveillance-Broadcast) has become popular as a means to assist pilots and controllers in gaining a more accurate picture of air traffic, weather, and terrain during a flight. Therefore, the Bluetooth low energy (BLE) systems will be utilized with the help of Automatic Dependent Surveillance Broadcast (ADS-B) for the Cloud based communication of the UAS. The flight paths of individual UAS units are combined with other spatially localized units to create a UAS swarm that naturally avoids collision through the synchronized movements of the swarm. UAS that implement this protocol would use Bluetooth Low Energy (BLE) communication to determine which other UAS units are in close proximity. In addition, BLE will be used by UAS to communicate in the absence of the wireless network. Units in close proximity communicate their desired flight path to each other. For UAS that are farther apart, satellite-based communication will be implemented to reach a broader range and ensure that communication is not lost between air traffic controllers and other aircraft.

<u>The UAS Monitoring and Communication Method</u>

The novelty of our system is to allow monitoring of real-time UAS sensor data, a visual display for current flight paths for multiple concurrent UAS flights and support for automatic collision avoidance. The UAS Flight Communicator architecture consists of three entities: the client, server and UAS. Normal operation of our system utilizes a single cloud-hosted server with a varying number of clients and UAS. The client includes UAS monitoring and UAS management modules that allow the user to control added UAS and receive real-time sensor updates, as well as user and server interfaces with which to communicate. Data from the server communication interface of the client system is passed to the UAS monitoring module for processing before being sent to the map and displayed on the user interface. With the help of the ADS-B, the current location and altitude of individual UAS are determined and therefore sent to the ground station, this enables other UAS to receive communications from the ground station, and act accordingly. The collision detection sub-module implements the collision detection algorithm by reading real-time sensor information from the database, checking for collisions and then preparing data to make the needed UAS path adjustments. The UAS path-adjusting sub-module receives collision information from the collision detection sub-module, performs the path adjustments and sends the updated path to the management module where it can be deployed to the UAS. The collision alerting sub-module reports detected collisions and adjusted path data to the collision management module of the client, where it can then be displayed to the user.

Problem-Solving Approach

Existing solutions for UAS communication utilizes radar based as the communication link. We aim to provide a Cloud-Based Communication Bluetooth Low Energy (BLE) in ADS-B solution that can leverage the power of highly distributed cloud computing platforms to provide a UAS communication and collision avoidance system suitable for thousands of concurrently connected UAS. To pursue our goal in this project, we will develop a scalable cloud-based control and management system for UAVs, called Cloud Based UAS Communicator (CBUC). The Cloud Based UAS Communicator will have a client and server model. The client allows the user to control added UAS, receive real-time sensor updates, communicate the visualized UAS and receive priority alerts in collision detection. The server provides sensor and collision information to the client, implements collision detection algorithms, manages user profiles and updates UAS control information. The contributions of this work are as follows:

1. Design of real-time flight monitoring, Communication and visualization of multiple UAS
2. Collision detection and avoidance with automatic adjustment of UAS flight paths
3. Scalability support via cloud systems
4. Implementation and performance simulation

Three different communication scenarios were considered for implementation:

1. Scenario #1: drone-to-drone collision (Figure 2)
2. Scenario #2: drone-to-taxi collision (Figure 3)
3. Scenario #3: taxi-to-taxi collision (Figure 4).

There is no human involvement within all of these scenarios. The wireless device utilized in all scenarios is called the Cloud-Based UAS Communicator (CBUC). In Scenario #1, each drone communicates through a wireless network utilizing the CBUC which verifies each drone. The drones receive flight information through the CBUC. Once the drones sense each other, they exchange flight data. After this, the Sense and Avoid (SAA) algorithm will engage so that the drones are able to determine which path to take to avoid collision while maintaining safe flight. Within the algorithm, different flight paths are examined. Flight paths that lead to negative results (i.e. collision), will fail and the SAA algorithm will have to restart. Once a flight path is chosen, each drone will broadcast the flight data which is received by the control system. If the wireless network is down, the system will rely on the ADS-B ground stations. Each drone will be able to communicate with ADS-B ground stations via the BLE controlling device integrated in their system. Since UAS in closer proximity are mainly considered and BLE requires low energy, the BLE controlling device will broadcast data at 2.4 GHz of the 978 MHz. Drones will be able to sense each other utilizing BLE communication. After this, the SAA algorithm will take effect and each drone will transmit the data received. The data is then sent back to the controlling device and then to the ADS-B ground station. In Scenario #2, a drone and a nearby taxi are considered. Each UAS communicates through a wireless network utilizing the CBUC which verifies each UAS. The taxi and drone receive flight information through the CBUC. Once the UAS sense each other, they exchange flight data. After this,a process similar to Scenario #1 will be followed. The same process is followed for Scenario #3, with the exception that there will be two taxis present instead of a taxi and a drone.

Risk Assessment

Some constraints to consider are cost, range, data throughput, and security as explained in Table 1. The risk assessment is completed through the guidance of SafetyCulture and *The Managers Resource Handbook* by MHX Global LLP. The risk matrix is adapted from SafetyCulture. The risk assessment process included in *The Managers Resource Handbook* incorporates the impact of a specified risk, as well as mitigation strategies of each risk [6]. The level of risk is measured by the probability of the risk occurring and the consequences of that risk occurring. The four consequence categories are: fatality, major injuries, minor injuries, and negligible injuries. The four probability categories are: very likely, likely, unlikely, and highly unlikely [5].

Risk	Description	Impact of Risk	Level of Risk	Mitigation Strategy
Cost	- Transitional costs from shifting to a cloud-based control system. [2]	No risk to human life or infrastructure.	Low	Apply for grants; Obtain sponsorships through partnerships.
Range	- In cloud-based systems, data communication can be disconnected due to possible network issues. Unpredictable computational lag can also affect system performance. In addition, increased server space usage can lead to slower performance. [2]	Could lead to risk to human life and infrastructure if this occurred during operation times.	High	Frequent network maintenance; Incorporate higher capacity servers.
	- BLE operates at 2.4 GHz and can be affected by surrounding obstacles. The orientation and design of the BLE device can also affect the performance. [3]	May lead to risk to human life and infrastructure if this occurred during operation times.	Medium	Limit surrounding obstacles; Ensure that the orientation of the device on the UAS is correct.
	- ADS-B depends on on-board navigation devices and on-board broadcast transmission systems to provide surveillance information. [4]	No risk to human life or infrastructure.	Low	Cloud-based communication will mainly be used except in the case that the wireless network is down.
Data Throughput	- The data rate at which BLE transmits data can be 1 Mbps for Bluetooth 4.2 and earlier versions. For Bluetooth 5 and later versions, the data rate can either be 1 Mbps or 2 Mbps. [3]	No risk to human life or infrastructure.	Low	Utilize Bluetooth 5 for higher data transmission speed.
	- For ADS-B, the aircraft/vehicle transmitting the broadcast may or may not have the knowledge that the users (ground-based or aircraft) receiving the broadcast have. [4]	May lead to risk to human life and infrastructure if this occurred during operation times.	Medium	Ensure that all systems involved are supplied with the necessary information for efficient flight.
Security	- Cybercriminals may target the cloud-based system. [2]	Could lead to risk to human life and infrastructure if this occurred during operation times.	High	Ensure that safeguards and security blocks are well-integrated in the cloud system.

Table 1 - Risk Assessment.

Impact Statement

Unmanned aerial systems can be used to support firefighting and search and rescue operations, to monitor and assess critical infrastructure, to provide disaster relief by transporting emergency medical supplies to remote locations, and to aid efforts to secure borders. Other applications of this technology include healthcare, transportation and logistics, infrastructure, economy, security, and the environment.

- Healthcare: Many rural regions around the world lack access to high quality healthcare. While medical supplies can be delivered by traditional means, certain circumstances such as catastrophe call for quick access to drugs, blood, and medical technology. Drones are effectively delivering biologicals like blood, serums, viral culture, vaccines and organs in the fastest and safest manner which is helping in saving millions of lives.
- Transportation and logistics: The transportation and logistics environment has taken to drones in several arenas because of their ability to maneuver around and above otherwise difficult to reach areas like warehouses and shipping container ports and terminals. And part of their repertoire includes multiple ways to communicate and share information. Cameras are standard equipment and are used not only to provide visibility to pilot the drones but also for identifying and inspecting items. Drone cameras are used to automatically read QR codes that identify shipping containers, machinery and manufacturing equipment, and they can be equipped with RFID scanners that let them locate or identify items not easily visible from the ground.
- Infrastructure: Maintenance and repair crews are using drones' high-resolution cameras to perform inspections of hard-to-reach locations like bridges, dams, and tunnels without putting a person in a dangerous situation. Drones can easily maneuver around structures at heights that previously weren't easily accessible by workers needing to take a close look at conditions. Drones are able to be quickly and accurately positioned to aim their cameras at areas of interest while workers on the ground use their tablets to control, view, inspect and document their observations.
- Economy: On a macroeconomic scale, the integration of UAVs could create more than 100,000 jobs. Over a 10-year span, job creation from commercial drone use will consist primarily of manufacturing jobs and drone operators. Likewise, states will benefit from tax windfalls, stemming from increased economic activity. The implications clearly have a positive impact on businesses and consumers. Consumers directly benefit from job creation, resulting in additional earnings. Commercial drones will also allow industries to realize savings from cost-effective means of inventory, transportation, and distribution. These cost savings can be passed down to the consumer through a reduction in prices.
- Security: By the very nature of remotely operated devices, drones do not require an on-site team. Providing aerial surveillance all day, every day, security and safety teams can schedule remote patrols and follow the drone's trajectory and video feedback in real time via their remote devices.
- Environmental: The environmental impact is also immense. Powered by batteries, drones are more environmentally friendly than delivery trucks. If delivery drones gain widespread usage, this would reduce the reliance on vehicles for many companies. The impact on the environment would be a boon and would help many countries reduce emissions, helping meet emissions targets set in various global agreements. [7-9]

Cost to Implement and Project Schedule

The project is estimated to take 6 months in order to conduct simulation, prototype assembly, and prototype testing/re-testing. In addition, the team must take into account the university's social distancing requirements.

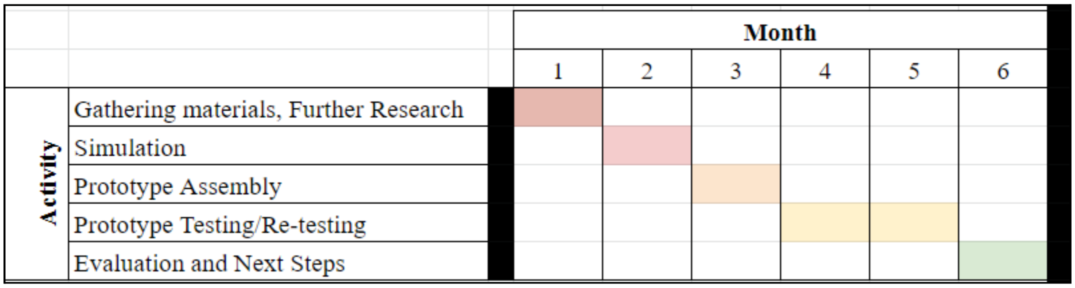

Figure 1 - Project Schedule

Item	Detail	Qty	Price ($)
Bluetooth Low Energy Device	Accelerometer+Inclinometer BWT901CL MPU9250 High-Precision 9-Axis Gyroscope+Angle(XY 0.05° Accuracy)+Magnetometer with Kalman Filter, 200Hz High-Stability 3-axis IMU Sensor. $45.99 each	3	137.97
UAS (Drones)	[Bluetooth Accelerometer+Inclinometer] BWT901CL MPU9250 High-Precision 9-Axis Gyroscope+Angle(XY 0.05° Accuracy)+Magnetometer with Kalman Filter, 200Hz High-Stability 3-axis IMU Sensor. $299.99 each	3	899.97
Cloud-Based Interface Enabled Device	Amazon EC2 Service; Amazon Web Services (AWS) Support Monthly Subscription. $243.61/month	6 months	1,461.66
Ultrasonic Sensor	5pcs HC-SR04 Ultrasonic Sensor, Distance Sensor with Ultrasonic Transmitter and Receiver Module Compatible. $15.99 each	2	31.98
Infrared Sensor	Sharp GP2Y0A21YK0F GP2Y0A21 10~80cm Infrared Proximity Distance Sensor. $9.88 each	3	29.64
Total Cost of Implementation			**$2,561.22**

Table 2 - Cost of materials. [10, 13-17]

Project Description, Section II
Demonstration Materials

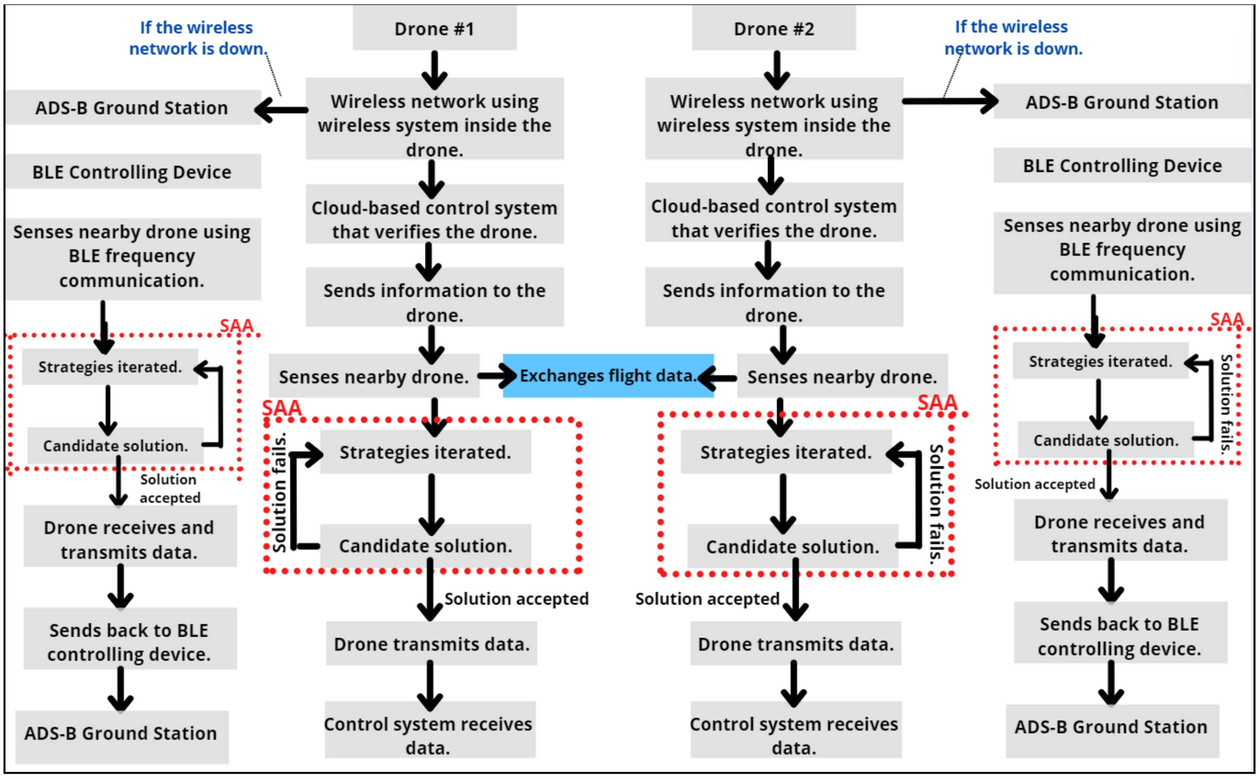

Figure 2 - Scenario #1: Drone-to-Drone Collision

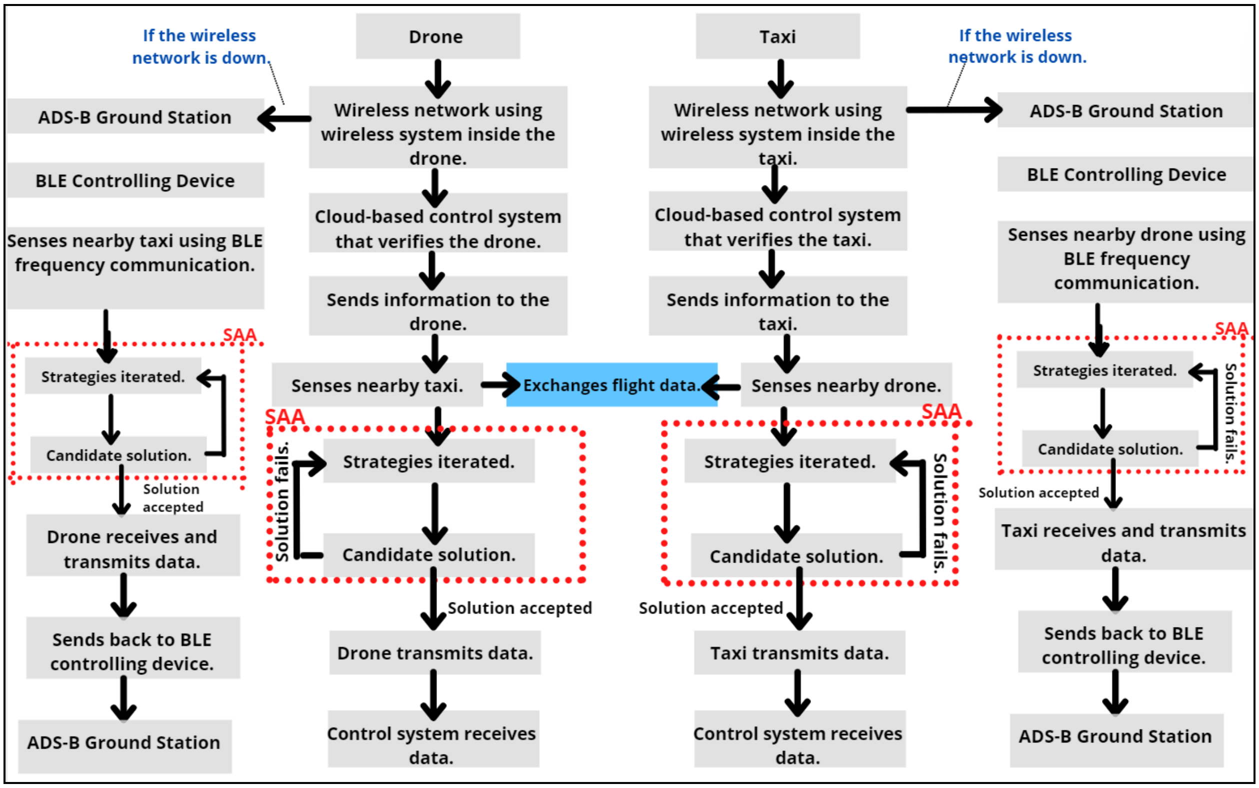

Figure 3 - Scenario #2: Drone-to-Taxi Collision

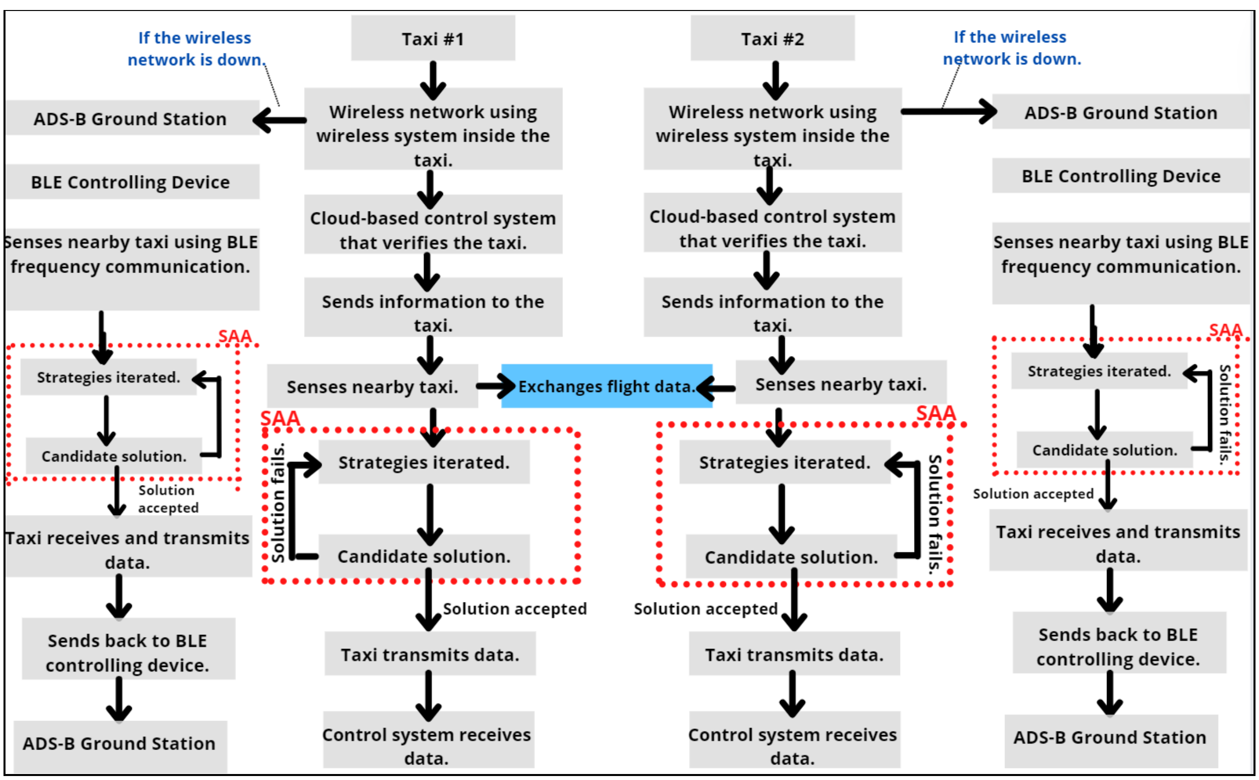

Figure 4 - Scenario #3: Taxi-to-Taxi Collision

Appendix

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[Reduced Weight, Less Than 0.55lbs / 249 gram Mini Drone, Improved Scale 5 Wind Resistance, Gray : Toys & Games]

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Optional

Videos/Images/Animations

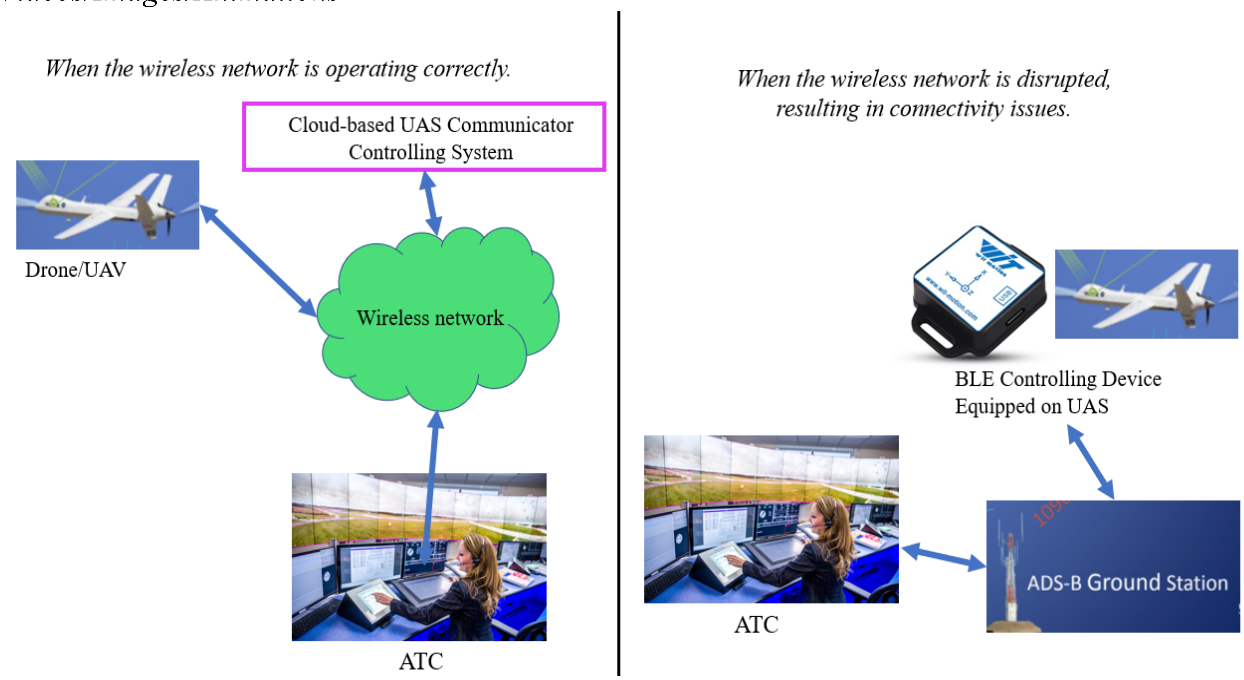


Figure 5 - Schematic of the Cloud-Based Communication BLE System in ADS-B. [11-12, 16]

University Support Letter

MORGAN STATE UNIVERSITY

Department of Civil Engineering, School of Engineering
CBEIS Room 101B
Baltimore, Maryland 21251-0001
Phone: 443-885-3293, Fax: 443-885-8218

1/20/2022

Shelley Spears, Director
Education & Outreach at The National Institute of Aerospace
National Institute of Aerospace
Office of Education and Outreach
1100 Exploration Way
Hampton, Virginia 23666

Dear Dir. Shelley Spears:

I would like to write this letter in support of the team of Morgan State University (MSU) competing in the 2022 FAA Challenge: Smart Connected Aviation Student Competition.

The project, titled "A Simulation of a Real-Time Cloud-Based Communication Bluetooth Low Energy System in Automatic Dependent Surveillance Broadcast (ADS-B) for Unmanned Aerial Systems" is led by faculty advisor(s), Drs. O. Owolabi, K. Nyarko, and N. B. Shourabi.

The project is to be fully supported by the Department of Civil Engineering at MSU if the proposal is favorably considered. Facilities, resources, and equipment at MSU will be made available to the faculty advisors and student team members as needed to successfully design, build, and test their proposed concept. The full research and results of the team's project will be presented during the FAA Challenge Forum, which is scheduled in June 2022. Assistance will be provided to facilitate processing travel reimbursements for the team members. Academic accommodations, if necessary and requested in advance, can be provided so that student participants may attend the FAA Challenge Forum.

Sincerely,

Jiang Li, Ph.D.
Professor and Departmental Chair of Civil Engineering
DOE Samuel P. Massie Chair of Excellence

Quad Chart

A Simulation of a Real-Time Cloud-Based Communication Bluetooth Low Energy (BLE) System in Automatic Dependent Surveillance Broadcast (ADS-B) for Unmanned Aerial Systems (UAS)

MORGAN STATE UNIVERSITY

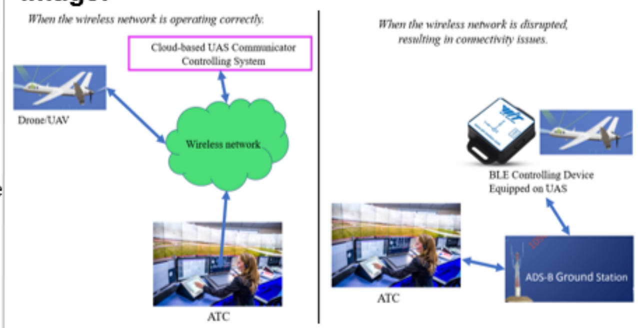
Objective and Description of Effort:

- To address the need for a scalable UAS communication and collision avoidance system by providing a web application that can leverage the power of highly distributed, cloud-based communication BLE systems.

Technical Approach:

- Develop a Cloud Based UAS Communicator (CBUC). The CBUC will have a client and server model. The client allows the user to control added UAS, receive real-time sensor updates, communicate the visualized UAS and receive priority alerts in collision detection. The server provides sensor and collision information to the client, implements collision detection algorithms, manages user profiles, and updates UAS control information.

Image:



Team & Management Approach:

- Maia Freeman – Graduate, Team Lead
- Lionel Thierry Fossi Tapong – Post-Graduate, Team Member
- Academic Advisors: Dr. Oludare Owolabi, Dr. Kofi Nyarko, Dr. Neda Bazyar Shourabi
- Management Approach
    - Team members will collaborate on completing the project. Team members will seek faculty assistance when necessary. The team lead will ensure that project milestones are being met with the help of the team member.

Schedule:

		Month					
		1	2	3	4	5	6
Activity	Gathering materials, Further Research						
	Simulation						
	Prototype Assembly						
	Prototype Testing/Re-testing						
	Evaluation and Next Steps						

Cost:

- Total proposed budget: $2,561.22