Temasek Defence Systems Institute

Conceptualization and Analysis of Using Unmanned Aerial Vehicles as Communications Relays in a GPS-denied Environment

Author: CPT Eunice Ong Advisor: Dr Su Weilian Co-Advisor: Dr Anthony Pollman

Need Statement

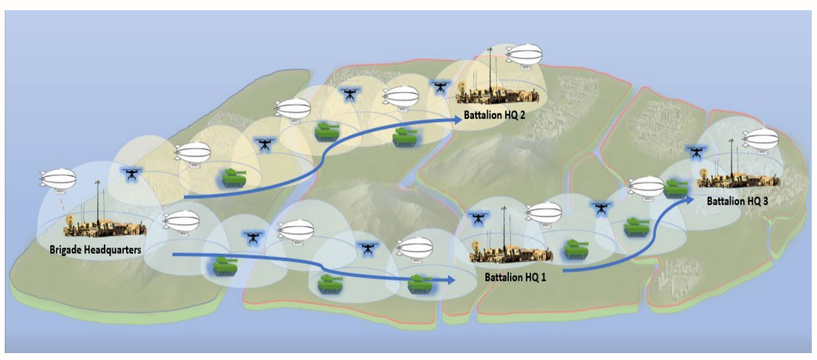
To replace manned static relay nodes with a robust network of unmanned aerial relay nodes to reduce the risks to and increase the survivability of the operators being deployed on the ground to bridge communication.

Thesis Objectives

The purpose of this thesis is to design an operational concept using UAVs as a proposed alternative means of communication relay system to extend the range of communication for tactical forces while overcoming the limitation posed by a GPS-denied environment. The findings of this thesis can be used to further enhance communication effectiveness in a combat operational environment. Considering the agility afforded by the UAVs and the flexibility of the wireless network to integrate and adopt new systems or algorithms to enhance the efficacy of signal of opportunity, this thesis addresses the following questions:

- What is the maximum communication range between two aerial relay nodes?
- How many aerial nodes are required to provide communication coverage for an area of 50 km by 50 km or the equivalent?
- What is the estimated effective data throughput between the aerial relay systems?

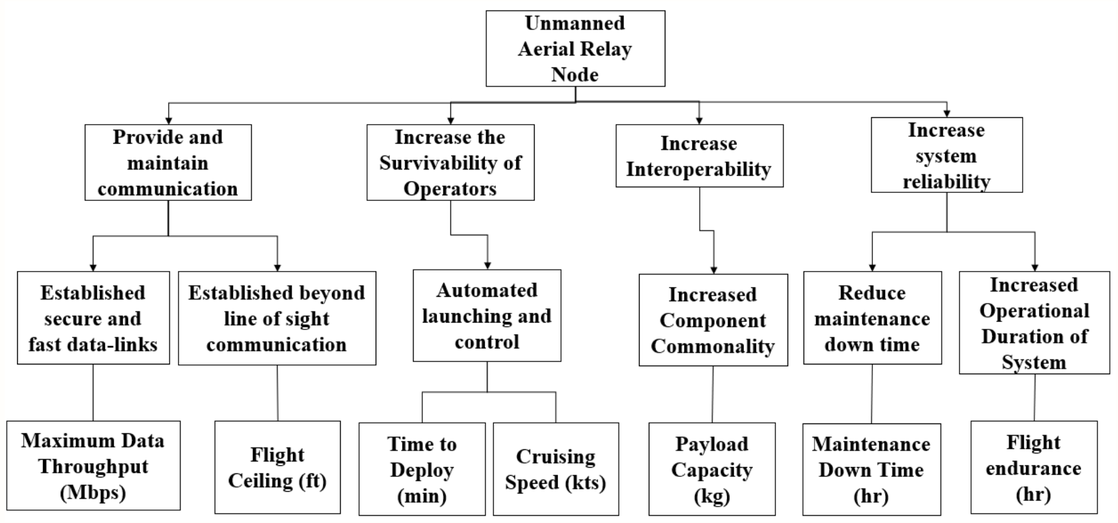
Conceptual Design



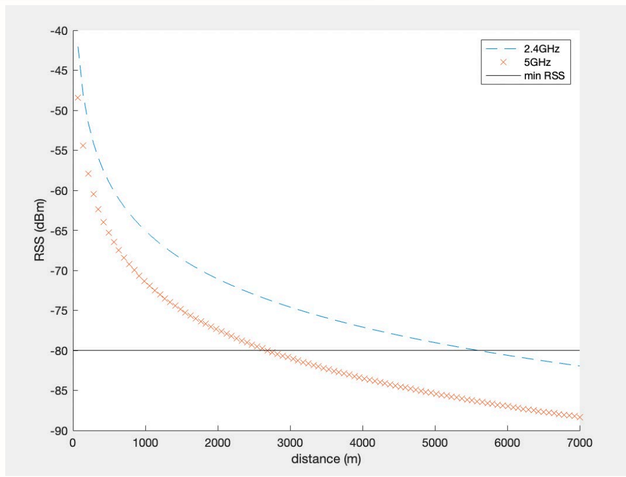
The central idea is to adopt a hybrid communication system that employs both the aerostat system and the tactical drones.

1. The aerostat system can be deployed by the troops as they transverse along preplanned route towards their target location.
    - providing communication and surveillance operations
2. To enhance the overall reliability of the communication network, tactical drones can be deployed to help bridge communication in the event that the aerostat system is down or when there is a need for larger bandwidth communication.
3. With the current technology and algorithms that are available, the drones can be autonomously deployed, and fly based on predetermined way points to their designated deployment site.

Value Hierarchy



Maximum Communication Range

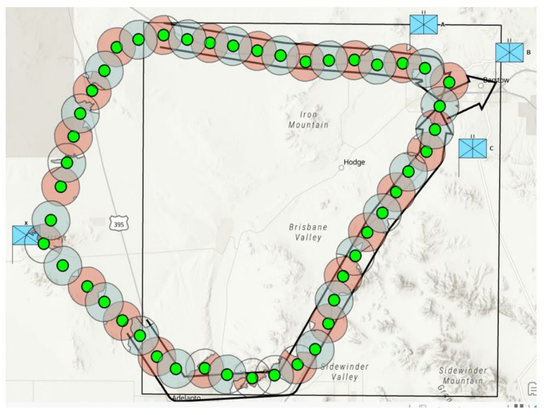


Setting the maximum ERP in accordance with the FCC ISM band regulation and setting the minimum RSSI threshold at -80dBm, it is possible to determine the maximum communication range between two nodes transmitting at 2.4 GHz and 5 GHz, to be 5.5 respectively, using the Friis transmission equation and keeping the transmit power, P_{tx}, and transmit antenna gain, G_{tx}, at a constant of 30 dBm and 6 dBi, respectively.

Effective Application Throughput

Frequency		2.4 GHz		5.0 GHz	
		Simulation Result (@ 20 MHz Bandwidth)	MCS table (@ 40 MHz bandwidth)	Simulation Result (@ 20 MHz Bandwidth)	MCS Table (@ 160 MHz bandwidth)
Data throughput for IEEE 802.11ax (Mbps)		4.403	17.2	4.488	72.1
Data Exchange	Bit Rate	**Number of Channels**			
Voice Messages	64 kbps	68	268	70	1,126
Video feed	2 Mbps	2	8	2	36
Text Messages	0.224 kbps	19,656	76,785	20,035	321,875
Text Messages with Images	1 Mbps	4	17	4	72

Communication Coverage



Phases of Operation	Type of System	Frequency Band	Number of Assets
Phase 1:	Aerostat Communication Relay	2.4 GHz	23
Phase 2:	Aerostat Communication Relay	5.0 GHz	23
	Tactical Drone Communication Relay		24
Phase 3:	Aerostat Communication Relay	2.4 GHz	23

Future Work

1. Conduct real-life flight testing.
    - To have a better understanding and more accurate estimation of the effective throughput of the aerial relay network
2. Analysis of power consumption.
    - Given the limited amount of payload that the drone is capable to carry, there is a need to explore alternatives such as integrating a solar power system with the drones to prolong their flight duration and to power up the payload.
3. Integration with surveillance systems.
    - provide additional services such as conducting surveillance and reconnaissance missions if sensors and camera systems were installed on the relay nodes. To confirm this, it would first be necessary to determine whether the different systems integrated on the aerial relay nodes would cause interference.

Reference:

MathWorks, Inc. n.d. “802.11 MAC and Application Throughput Measurement - MATLAB & Simulink.” Accessed August 11, 2022. https://www.mathworks.com/help/wlan/ug/802-11-mac-and-application-throughput-measurement.html.

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