UAVs Swarming Overview

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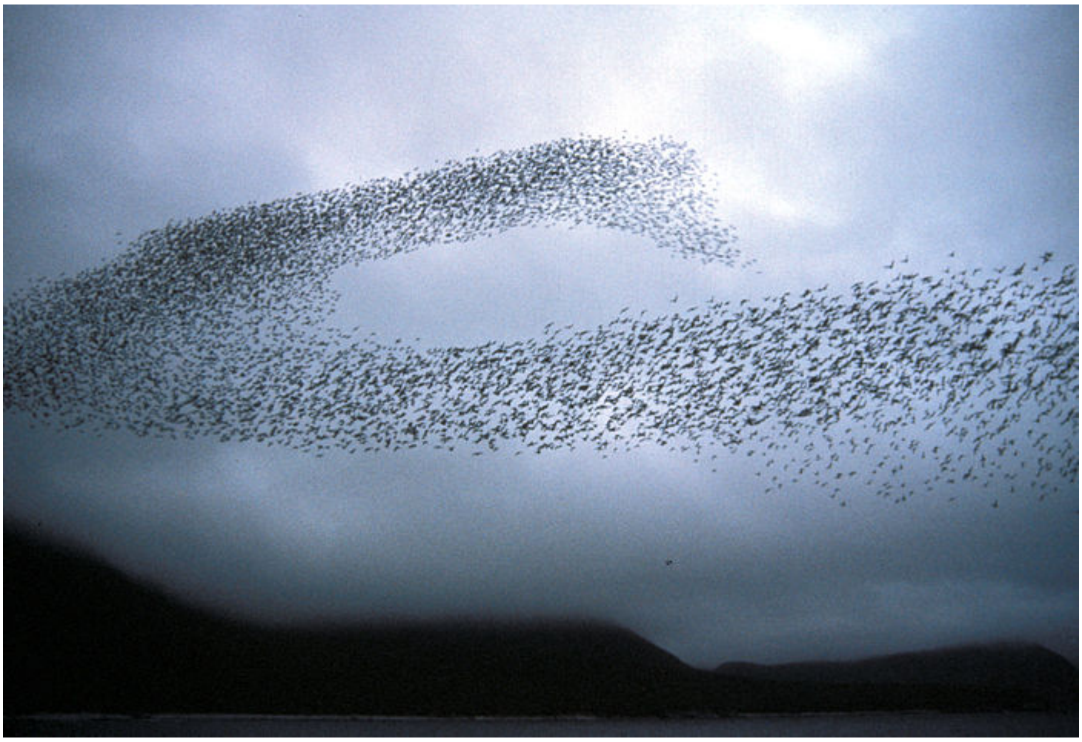
1. What is Swarming?



Swarming, is a collective behaviour exhibited by entities.

Swarm robotics is an approach to the coordination of multiple robots as a system which consist of large numbers of mostly simple physical robots. "In a robot swarm, the collective behavior of the robots results from local interactions between the robots and between the robots and the environment in which they act. It is supposed that a desired collective behavior emerges from the interactions between the robots and interactions of robots with the environment.As they have continuous feedback loop between them to coordinate them as swarm.

The common natural flocking phenomenon/behaviour which has been observed in birds, fishes, insects etc., without losing direction and without hitting obstacles or each other, is explored for the development of UAV swarm system

Communication is one of the most challenging issues for swarm UAV systems

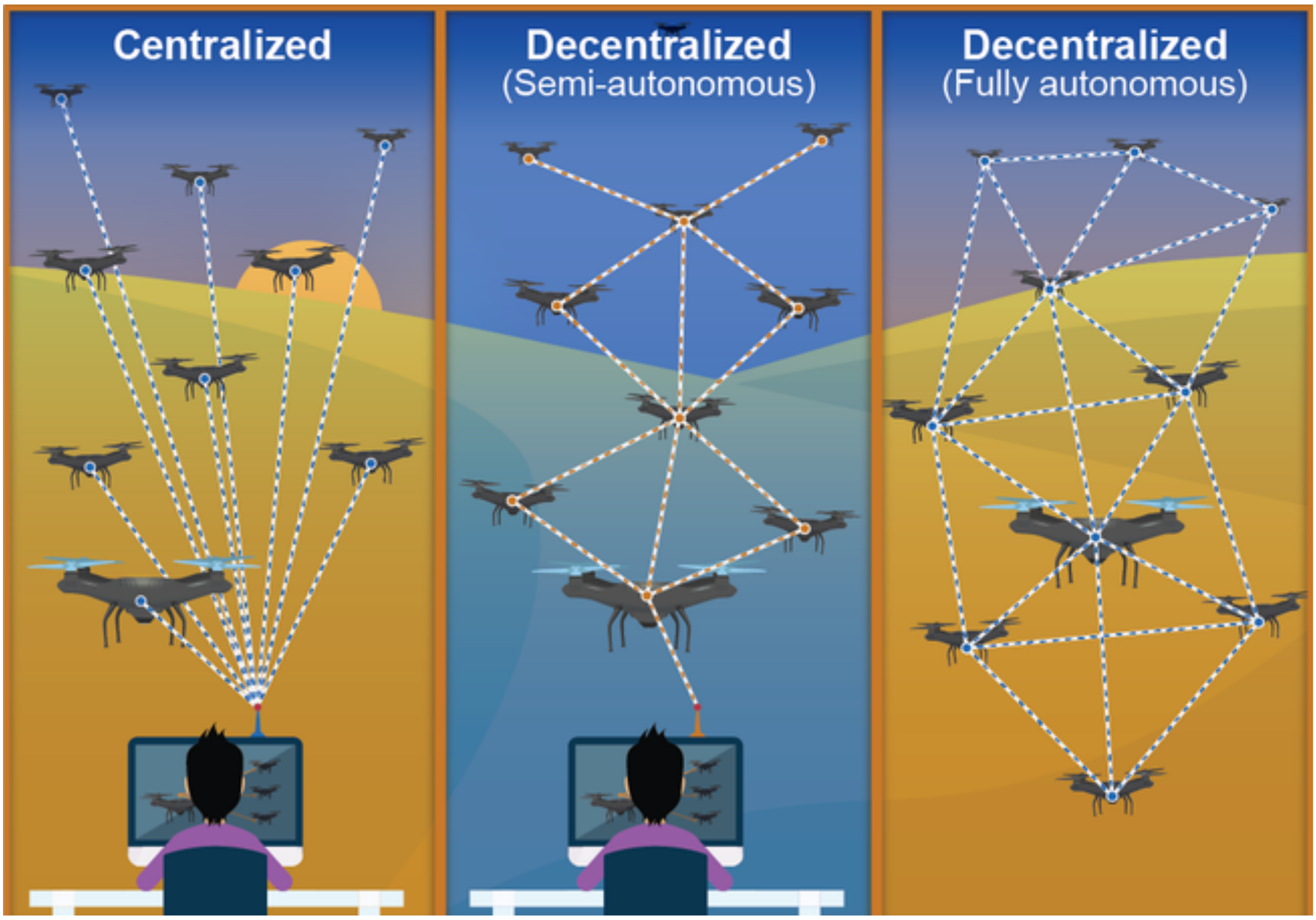
2. Introduction

Large number of UAVs/drones flying similar to flock of birds in order to perform coordinated tasks is known as swarm UAVs/drones. Reliable communication amongst swarm UAVs is most essential to achieve the coordination. The utility of UAVs in swarming is that they add more functionality and perform tasks addressing the limitations of single UAV.

Swarms give rise to a collective behavior distributed across many UAVs, and are capable of solving complex problems, resulting in a whole system greater than the sum of its parts. Advantages to swarm include time-savings, reduction in man-hours, reduction in labor, and a reduction in other costs. Swarm intelligent systems are robust, scalable, adaptable, and efficient problem solvers for several applications

The UAV fleets may be behave like swarms, where artificial intelligence (AI) algorithms designed for the swarm intelligence paradigm can be applied. swarm intelligence takes inspiration from the collective behaviour of natural systems, such as swarms of ants. These are inherently decentralized systems, having the ability to self-organise. The swarm's behaviour is often optimised using evolutionary algorithms based on swarm intelligence principles, such as (i.e., antcolony optimisation, bee-inspired algorithms and particle-swarm optimization). Autonomous swarm of UAVs may operate in remote locations with little or no control by a human operator but with communication capabilities. In autonomous UAVs swarm, multiple tasks can be performed simultaneously, and the workload can be distributed across the swarms.

3. Methods of Swarm UAVs Control



The UAV swarm system can be either remotely controlled or controlled by automation algorithm. For certain applications, UAV fleets are likely to act autonomously and can make in-flight decisions without requiring instructions from the GCS.For some applications, all decisions might be taken by the GCS, which require UAVs to communicate information in real-time to the ground, and to quickly respond to any received instructions.

3.1.1 Swarm Control Architectures:

Centralized control architectures rely upon ground infrastructure, limiting the capability of the swarm by tying it to a local area and increasing weight requirements.

Decentralized control permits the swarm to operate out of range of ground infrastructure, and to pass data to or from any swarm member with an external link to just one swarm member. There is a third path which combines these two methods, where one swarm member is designated the master which provides direction to the remainder. An architecture like this has been tested with some success, but at its lowest level each slave swarm member still must be able to communicate position and velocity data with the master

a key building block of an independent swarm is a decentralized ad-hoc network.

3.1.2 Swarm classification based on layer :

(i) single-layered swarms with every UAV being its own leader

(ii) multi-layered swarms with dedicated leader UAV at every layer, which report to their leader UAV at a higher layer; a ground control station (GCS) is the highest layer in this hierarchy.

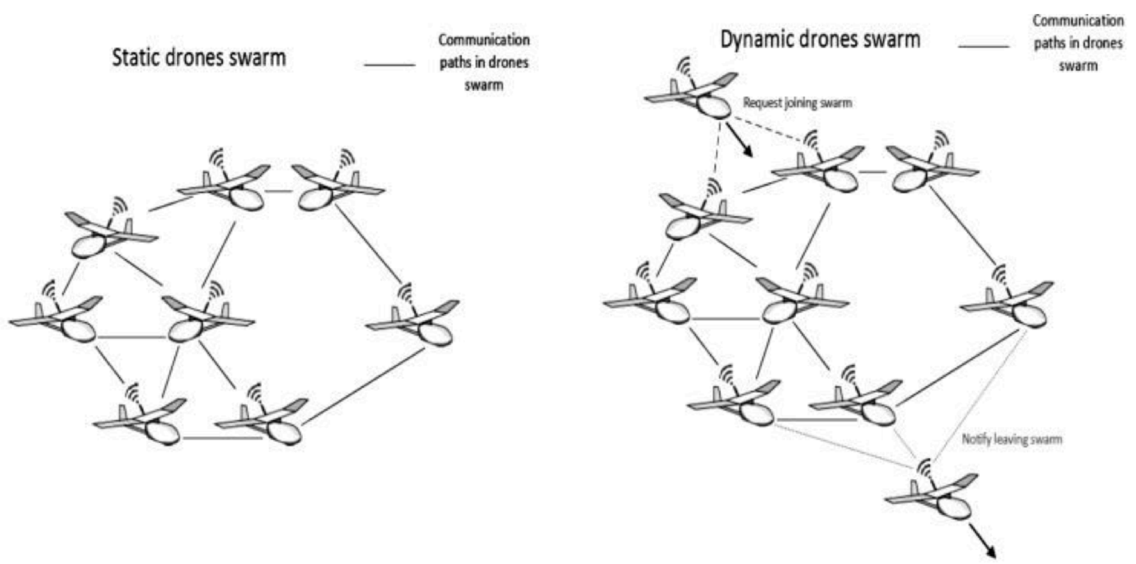
In each layered-swarm, every UAV will have dedicated data collection and processing with sufficient computing capability to perform these tasks in real-time. Its central processing takes place at the GCS. key building block of an independent swarm is a decentralized ad-hoc network.

The swarm classification can be further sub-divided as:

- Static swarm
- Dynamic swarm

The static swarm is the most basic type, where the members of the swarm are pre-selected at the pre-mission stage.During the flight operation, no new drone can be added into the swarm as the collective mission is locked at the mission center. It provides secure communication, mutual-trust and collaboration.

Dynamic swarm has the flexibility to add or remove a drone along with the existing group, at any time: pre-mission and/or during the mission. Such a system can either be a closed dynamic that only allows addition of new drones from the same organisation, or an open dynamic allowing addition of drones from a third-party organisations. The challenges of secure communication, mutual trust and collaboration are unique in comparison to static swarm.



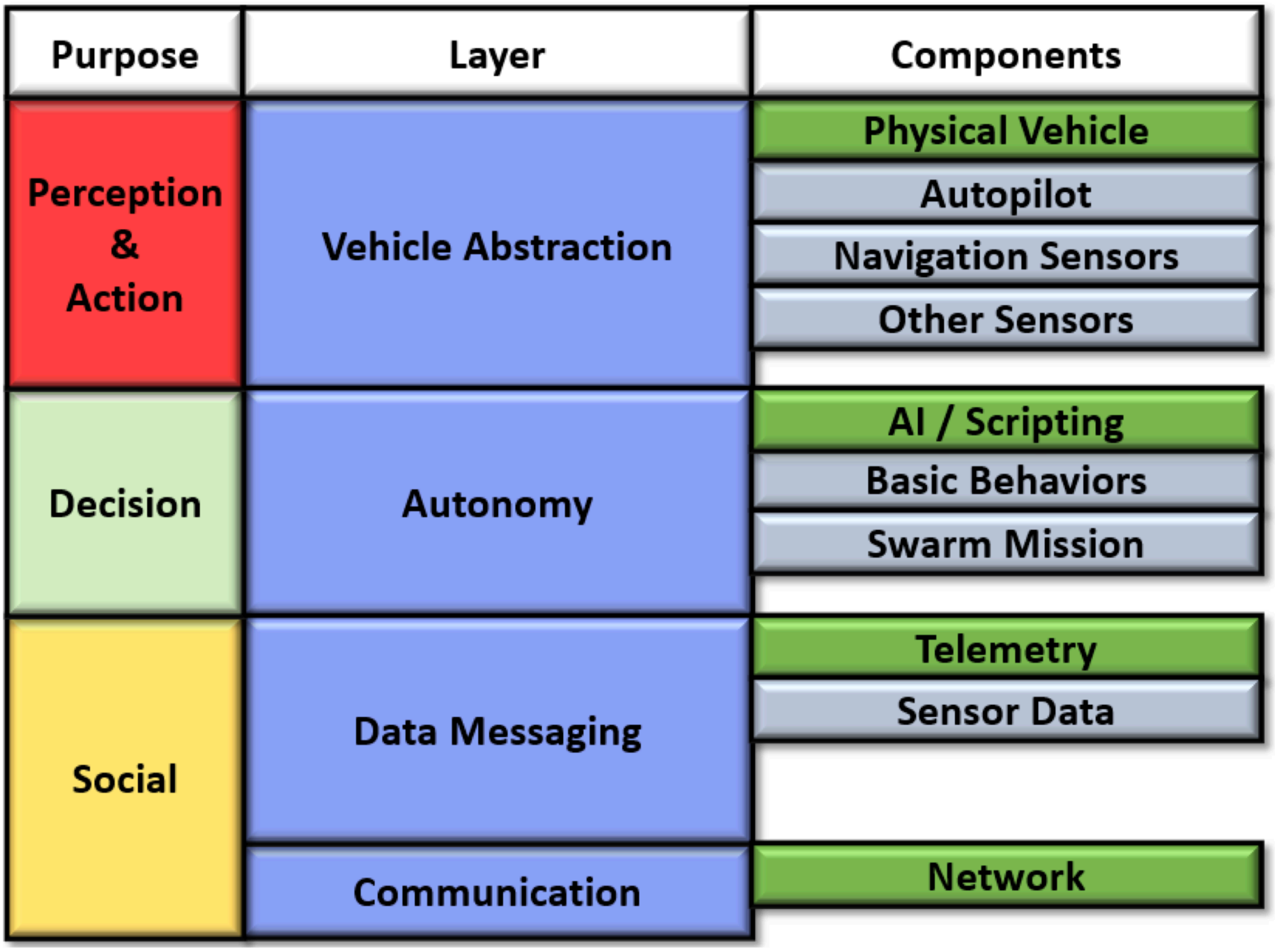


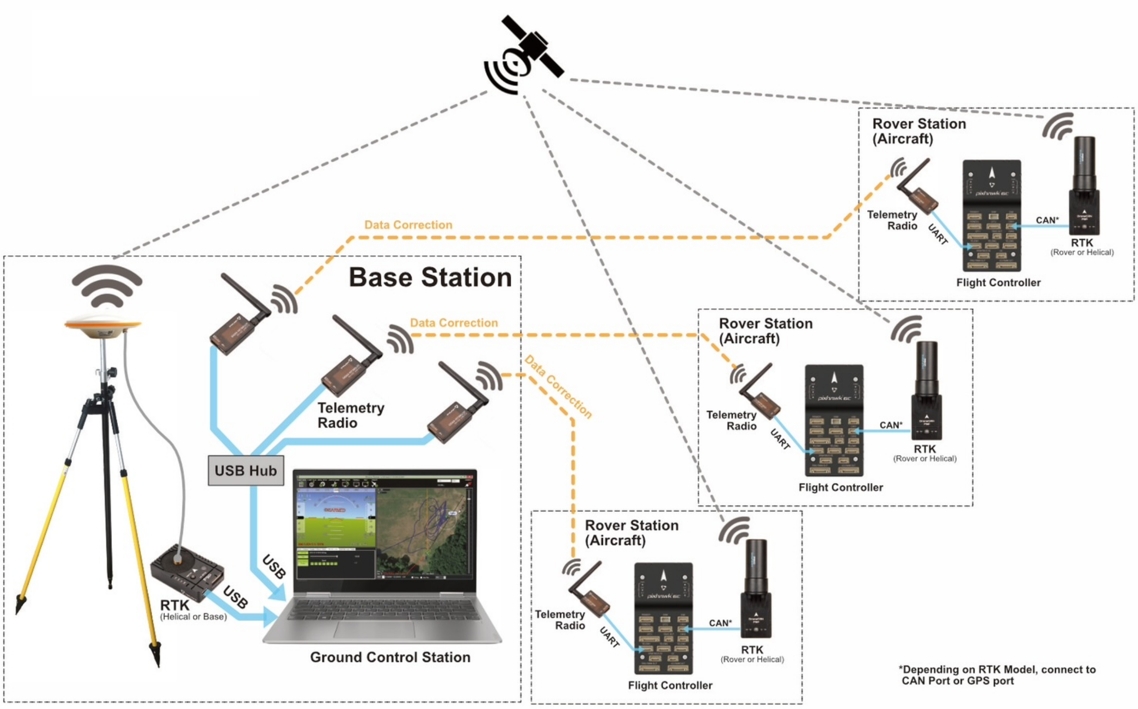
Fig - Swarm architecture

4. Swarm communication architectures

4.1 Infrastructure-based swarm architecture
4.2 FANET-based architecture
4.3 Mesh ad-hoc network architecture

4.1 Infrastructure-based swarm architecture(centralised)

The infrastructure-based architecture consists of a GCS that receives telemetry information from all drones in the swarm and sends commands back to each UAV individually. In some cases, the GCS communicates back to individual drones in real time, sending commands to the flight controllers on board each UAV. In other cases, a flight operation is pre-programmed aboard each UAV, which is simultaneously operated while the GCS is simply used to observe the systems. These UAV swarms still require direction from a central control to complete an assigned operation



Infrastructure-based swarm architectures are dependent upon the GCS for coordination of all drones. This dependency causes a lack of system redundancy. In the event of an attack or failure to any operation of the GCS, the operability of the entire swarm is compromised. Infrastructure-based methods require all UAVs to be within propagation range of the GCS. A drawback to unlicensed radio frequency communications is that communication may be susceptible to interference.

Because of the light payload capacities of sUAS, the hardware necessary to establish reliable communication with an infrastructure may limit the utility of infrastructure-based swarms. Another drawback is a lack of distributed decision making. In an infrastructure-based architecture, the GCS coordinates the decision-making of all UAVs based on computations and algorithms developed in the GCS.

4.2 FANET(Flying ad-hoc network)-based swarm architecture(decentralised)

This method uses multi-UAV systems for creating an ad-hoc network, popularly known as FANET, which minimizes the need of large infrastructure on the ground. In FANET network, a small number of UAVs communicate with the GCS while all other remaining UAVs communicate between UAV-to-UAV.

Small UAVs, being economical, have applications in several businesses, including civil and military applications. The FANETs are also being deployed in areas, such as traffic management, security & surveillance, precision agricultural, forest fire, and relay networks. These swarm UAVs offer several advantages, such as faster exchange of information, less time to complete work, cost-effective, reliability of data, and greater possibility for scalability.

The biggest issue for FANET is to provide all-time access to network resources at any given location. A wireless ad-hoc network is a wireless network that does not rely on existing infrastructure to establish the network. No routers or access points are needed for an ad-hoc network. Instead, nodes are dynamically assigned and reassigned based on dynamic routing algorithms. In several critical applications, such as disaster recovery operations due to an earthquake or flood, the use of FANETs becomes even much more challenging, where real-time data/information transmission is essential all the day. Thus, advanced technology related to wireless communication are required to be developed that is not only economical but also can be adopted for faster data communication with UAV-to-UAV and/or UAV-to-GCS. With the development in ICT, faster wireless communication technologies are also being developed; thus enhancing the potentials of smaller-sized UAVs for FANET-based applications in future.

The FANETs can also communicate with other networks, e.g., via satellite or cellular system. The FANETs, mainly due to their greater mobility, minimum central control required, and flexibility of structure, can be used to enhance the connectivity and communication range in those areas that have limited or poor cellular infrastructure . A relaying network of FANETs can be used to maintain a reliable connection between remote transmitters and receivers that are not able to directly communicate either due to larger distance or obstacles present between them.

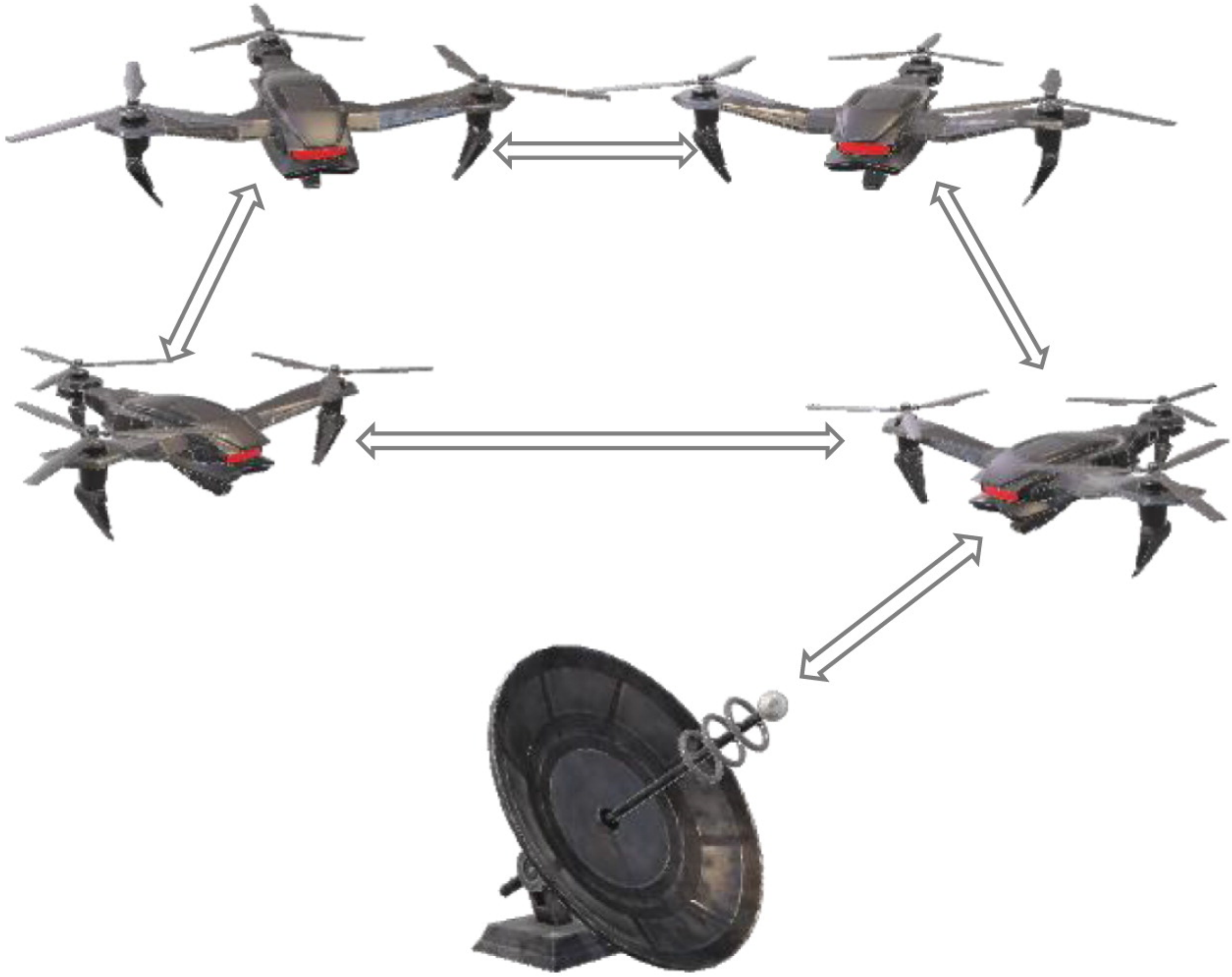


Fig. Communication architecture of UAV swarm based on FANET.

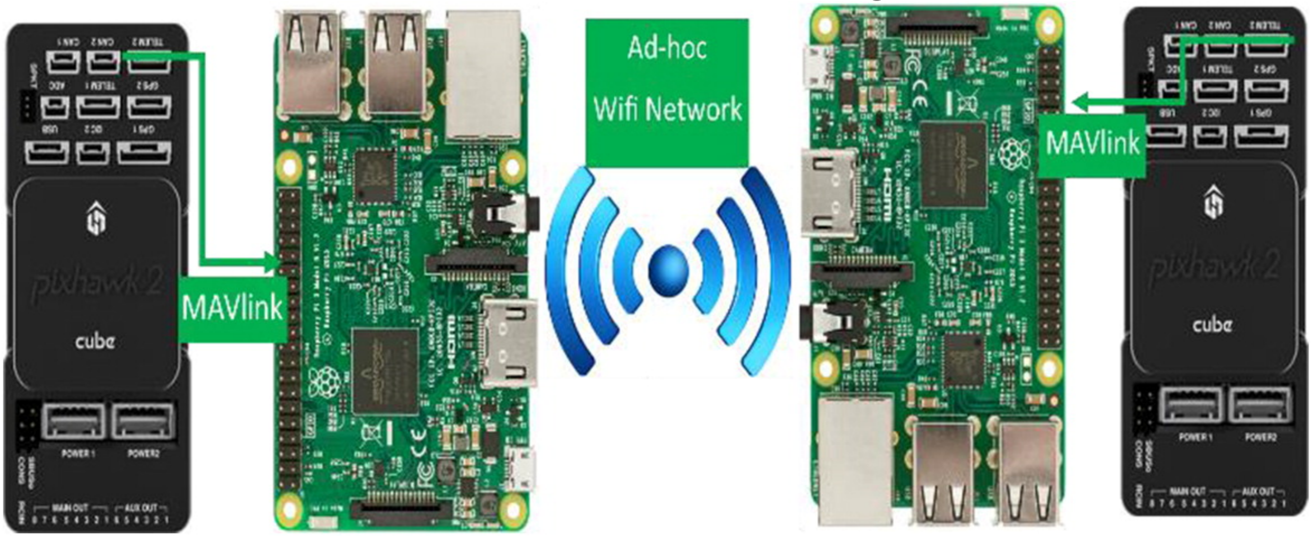
To establish a FANET, networking hardware is required on board each UAV. The distance over which UAVs can reliably communicate with one another in a FANET is a limiting factor to its implementation. Dynamic reconfiguration of routing for UAV swarm applications is a challenging task resulting in packet loss. For applications where accurate telemetry of data between UAVs is critical, the establishment of a reliable FANET is difficult. This work proposes a hybrid of an infrastructure-based network making use of cellular wireless communications infrastructure but establishing network protocol between drones without intervention of a GCS. This proposed architecture of UAV swarms leverages strengths of both architectures while mitigating some weaknesses.

4.2.1 UAV-to-UAV network communication test bed

The test bed developed uses custom built quadcopters. The quadcopters feature flight controllers interfacing with on-board companion computers and mesh networking hardware. The flight controller communicates with the on-board computer using Micro Air Vehicle Link (MAVLink) communication protocol. The companion computer understands MavLink telemetry through MavProxy software. MAVLink is the header-only, message-marshalling library used as the communication protocol between the ground station and UAV. The main components of a MAVLink message are the header, system ID, message ID, and payload. The header is used to classify the message as a MAVLink packet. The system ID identifies the system sending the message while the message ID identifies the type of message being sent. For example, the most common message to send is the heartbeat (ID = 0), which is constantly sent to ensure that the plane and ground station are properly connected and communicating. The payload of the message is the content inside it. The payload can contain fields, such as the vehicle type, flight mode, positioning data, or commands to execute. These messages are sent as data packets between the ground station and UAV to properly fly the UAV.

The flight control stack is open source and allows for custom development of control methods. The companion computer and networking capabilities allow for the development of flight control methods based upon data that is received from other UAVs in the network. Figure below displays a functional block diagram of the communication protocol from flight controller and companion computer of one UAV to the flight controller of another UAV. Currently simple tasks, such as swarms of UAVs that follow each other have been demonstrated. More complex tasks and the methodologies surrounding the achievement of those will be the subject of future publications. The key to this publication is the establishment of a reliable infrastructure for swarm communications. The proposition of cellular wireless infrastructure is promising in solving many limiting factors experienced in preliminary development of autonomous UAV swarm. With the proper regulatory framework and continued technology integration this architecture is promising.

UAV-to-UAV communication hardware diagram.



4.3 Mesh ad-hoc network architecture

Mesh Networking, also know as Mesh Routing happens at OSI layer 3, the network layer. Mesh Routing allows each device on a network (also called nodes) to act as a router and re-transmit packets on behalf of any other devices. Mesh Routing provide the multi-hop facility that Ad-Hoc mode lacks. By combining Ad-Hoc mode at layer 1 and Mesh Routing at layer 3 we can create wireless mesh networks purely between client devices without any need for centralized Access Points or Routers.

4.3.1 HARDWARE CONFIGURATION

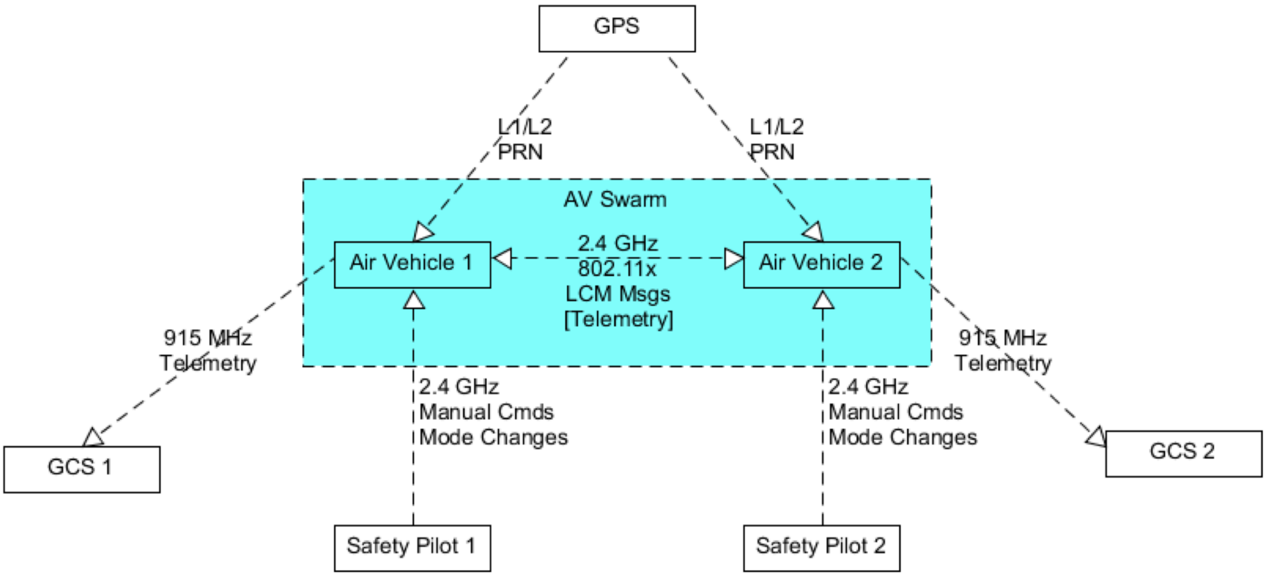
DRONE SWARM SET I: OCTAQUAD X-8 MULTIROTOR AIRCRAFT

AUTOPILOT SYSTEM: 3D Robotics Pixhawk autopilot

ON BOARD COMPUTING SYSTEM (COMPANION COMPUTER): Beaglebone Black

This project need a high performance companion computer to do mission planning, computer vision task, and other computing-intensive tasks.

COMMUNICATION SYSTEM:

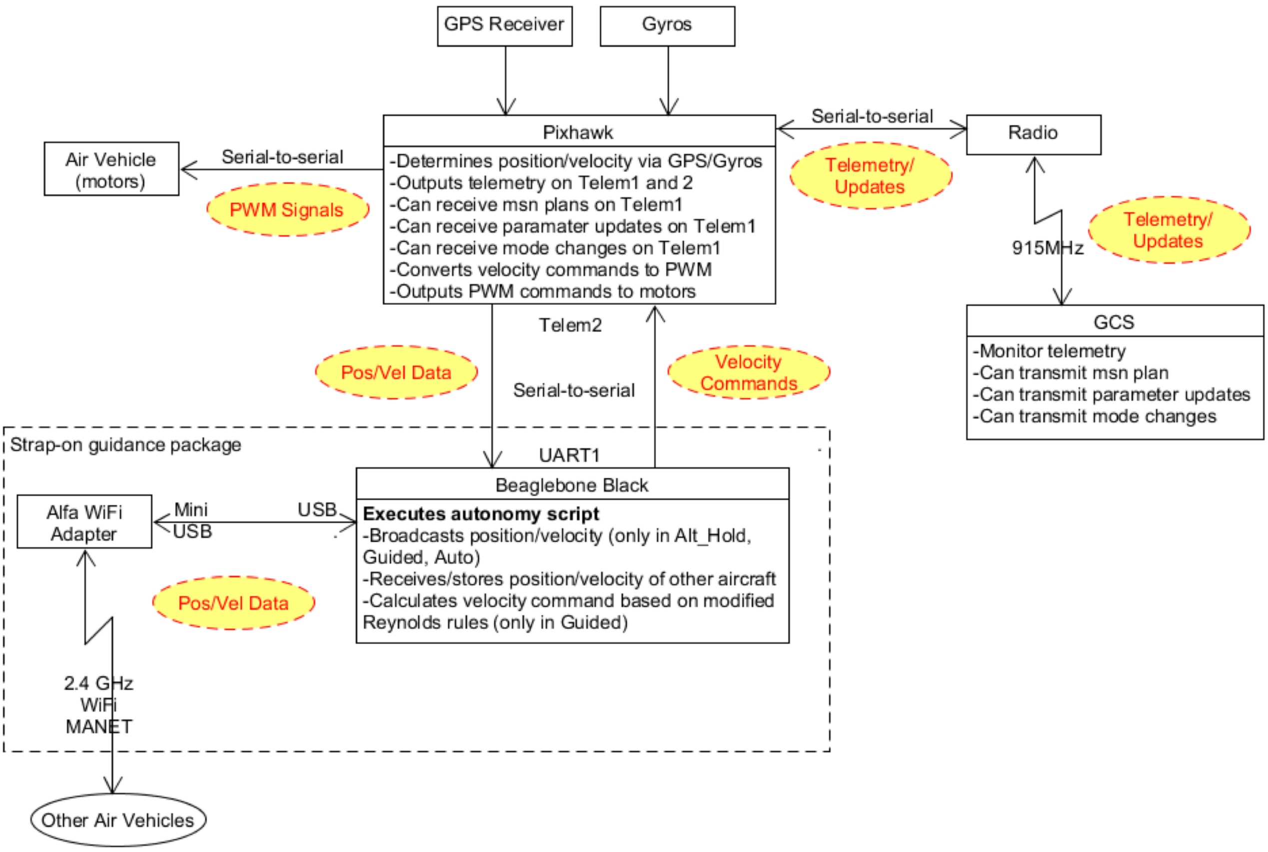


The X-8s each include two radios: one 915 MHz radio for connecting to a GCS, and one 2.4 GHz radio for manual control by the safety pilot.

COMMUNICATION WITH OTHER DRONES:WIFI VIA GROUND-BASED WIRELESS ROUTER

Beaglebone Black companion computer, an Alfa AWUS036NHA Wi-Fi adapter, a two-cell 2200 mAH Lithium-Polymer (LiPo) battery, and a voltage regulator.

The Companion computer with wifi adapter , and interfaces directly with the Pixhawk autopilot through a custom serial cable. The serial cable connects the UART1 port on the Beaglebone Black to the Telem2 port on the Pixhawk. The block diagram in Figure shows the physical elements comprising the air vehicle, the various interfaces and data links, and the information that flows between components.



Regarding the software, the Pixhawk autopilot is running APM: Copter version 3.4.6. The companion computer is running a Debian Operating System (OS) but any Linux distribution will suffice. The connection to the Pixhawk from the companion computer is made through DroneKit-Python, so all autonomy scripting is also written in Python. BATMAN-Advanced is used to set up the mesh ad-hoc network using the Alfa Wi-Fi adapters, and a script was written to automatically connect to the network upon powering the companion computer. The Lightweight Communications and Marshalling (LCM) library was chosen to facilitate UDP multicast over the network due to its flexible nature and also for data collection as it contains native data-logging capability

5. Telemetry Hardware:

5.1 RFD900x:

The RFD900x radio modem can be loaded with three official firmware releases to achieve different communication architectures and node topologies. So far, the available firmware versions are:

- Peer-to-peer (P2P)
- Multipoint network
- Asynchronous mesh

The RFD900x Radio Modem has many software features including:

- Frequency Hopping Spread Spectrum
- Transparent Serial Link
- Configuration by simple AT commands for local radio, RT Commands for remote radio
- User configurable serial data rates and air data rates
- Error correction routines, MAVLink protocol framing (user selectable)
- MAVLink radio status reporting (Local RSSI, Remote RSSI, Local Noise, Remote Noise)
- Automatic antenna diversity switching on a packet basis in real-time
- Automatic duty cycle throttling based on radio temperature to avoid overheating

Multipoint Network

The multipoint mode requires the firmware to be loaded into the all network radios.It is possible to run up to three networks of the same configuration at the same time to enable support for more nodes. There will still only be one master node (network 0, node 1) and all nodes will need to be in range of the master for synchronisation. Node 1 on network 7 or 13 will act as normal nodes. Nodes will only see other nodes on the same NetworkID.

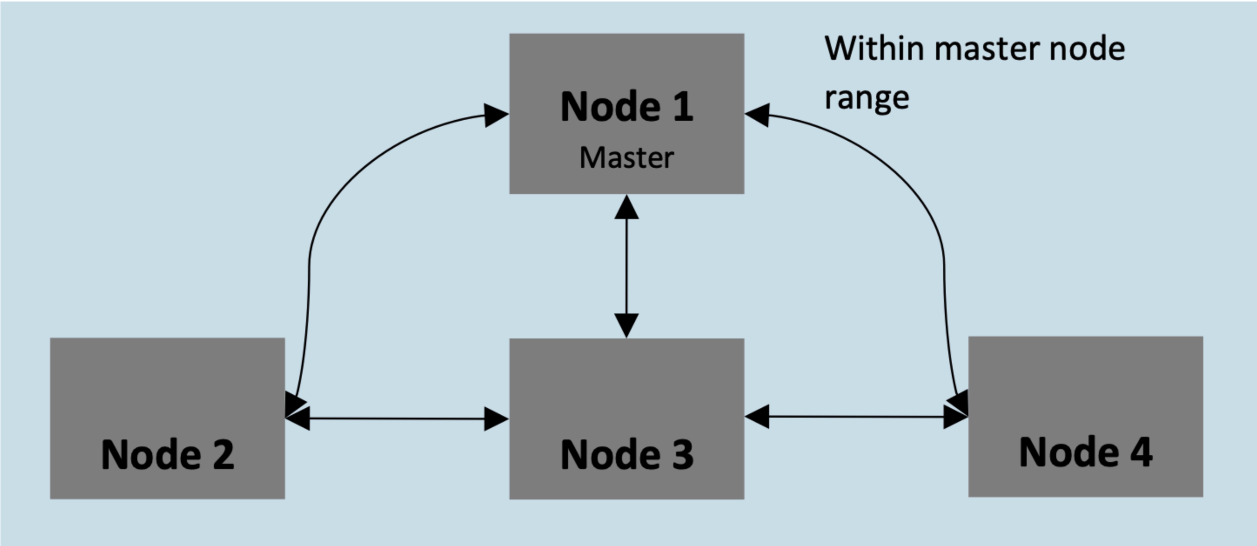


Figure 1-1: Multipoint network architecture

5.2 Robsense SwarmLink:

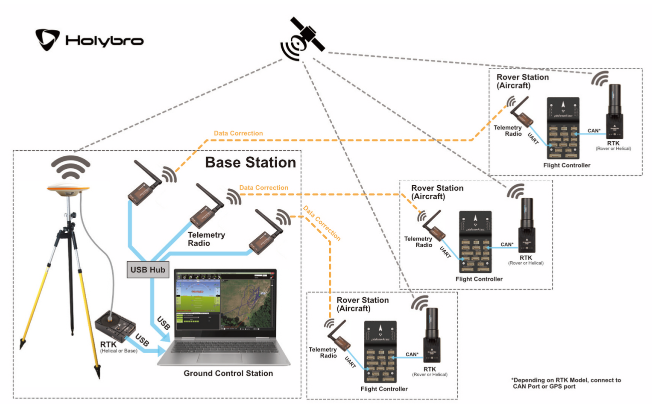
Robsense SwarmLink telemetry radios allows connecting multiple drones to a single ground station without the need for multiple radios on the ground station side (i.e. it creates a mesh network). Network monitoring and configuration software is also included.

For more information- https://ardupilot.org/copter/docs/common-telemetry-robsense-swarmlink.html

5.3 Sik Radio:

Multiple Point to Point Setup with Sik Radio:

You can use multiple Point to Point telemetry modules with the Holybro SiK Telemetry Radio V3.



For more information:
https://docs.holybro.com/radio/sik-telemetry-radio-v3/multiple-point-to-point-setup-with-sik-radio

7. SITL:


Mission Planner 1.3.81 build 1.3.8741.25556
DATA
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SETUP
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115200
Stats...
TCP5770-2-QUADROTO
DISCONNECT
Distance: 0.2044 km
Prev: 114.85 m AZ: 173
Home: 62.03 m
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MISSION
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GEO
SRTM
-35.3634054
149.165236
587.26m
Grid
View KML
GoogleSatelliteMap
Status: loaded tiles
Load File
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Write
Write Fast
Home Location
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Long 149.1652412
ASL 587.06
Use Ctrl + Click to show and hide Altitude Angel map information on the flight planning map.
WP Radius 2.00
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1 WAYPOINT 0 0 0 0 -35.3632872 149.16522... 100 Relative X 204.8 64.0 111.3 181
2 WAYPOINT 0 0 0 0 -35.3623817 149.16507... 100 Relative X 0.0 0.0 101.6 352
GEO -35.3625031 149.1650986 100.00m
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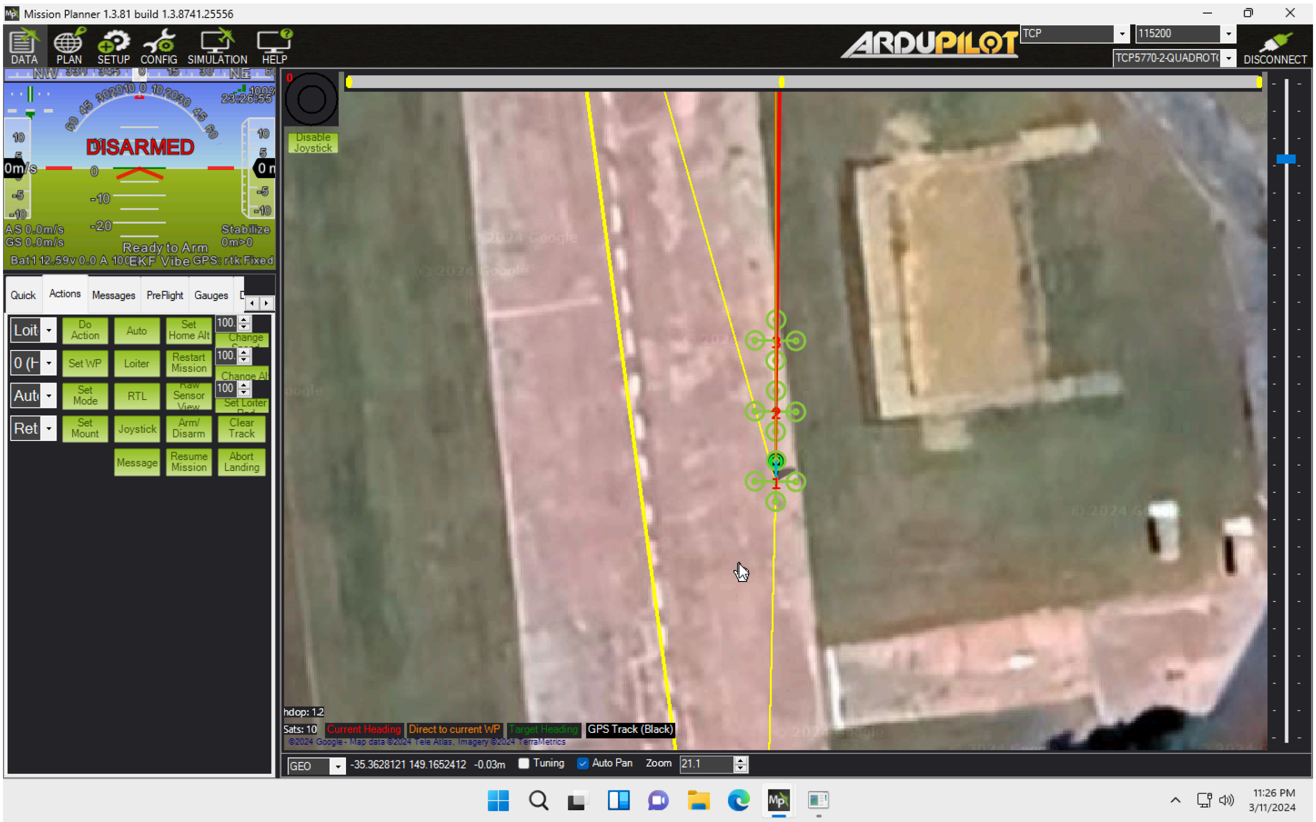
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Auto
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Change
Set WP
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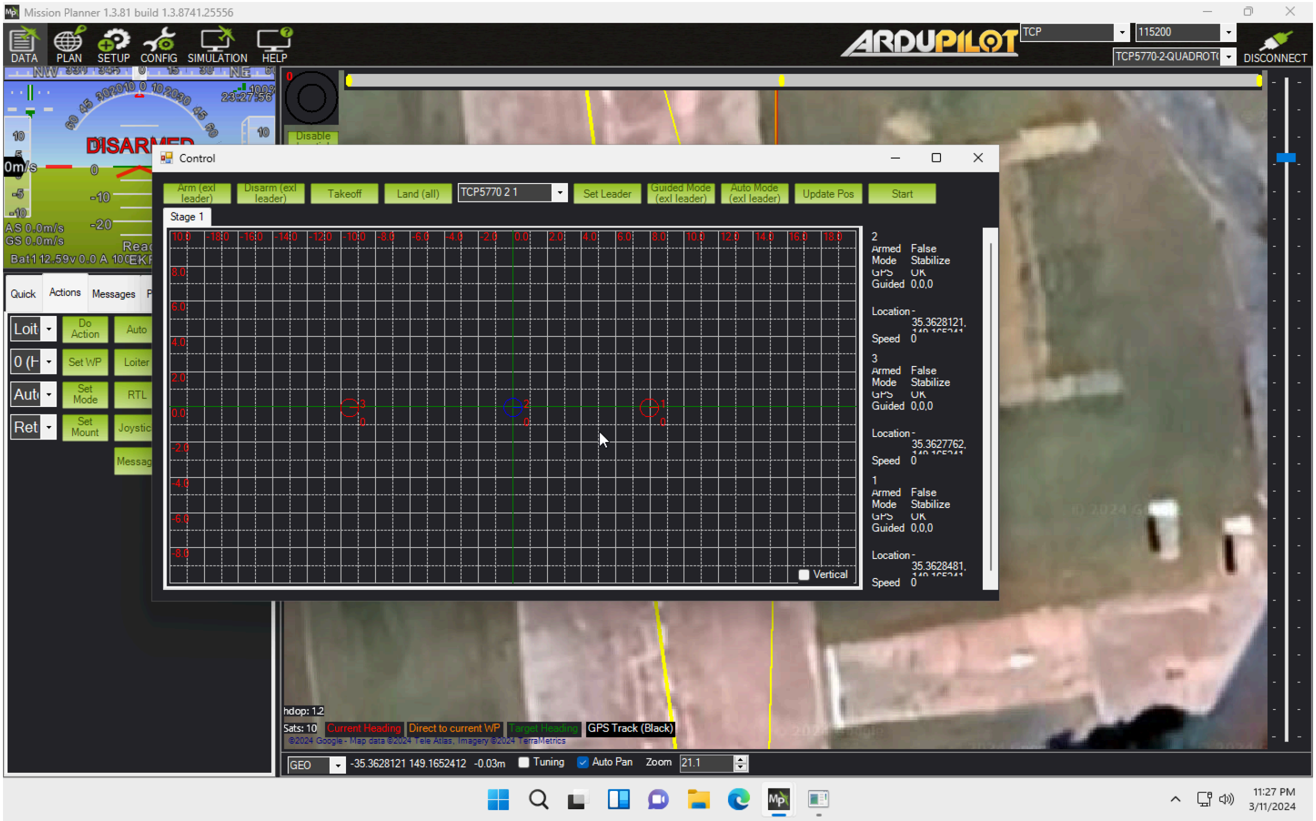

Google drive link:-
https://drive.google.com/drive/folders/18eVh-cIu9RtUB4igBsP3v3JVYRLIM21q?usp=sharing

8. FUTURE WORK:

The machine learning algorithm should be added for object detection module. Some advanced hardware features such as 360 degree lidar scanner should be implemented.

- Add Machine Learning Algorithm to Object Detection Module.
- Improve Stereo Vision System.
- Develop Obstacle Avoidance Feature with 360 degree lidar scanner.
- Develop SLAM Algorithm.
- Auto Re-configuration.

9. Conclusion:

This report provides a concept-level understanding , initial development, and literature review for the use of network as the communication infrastructure for UAV swarms. It provides an overview of the UAV swarming communication architecture fits best , the applications of UAV swarm, and in-house development efforts for UAV swarm. The paper reviews preliminary test bed developments and provides direction for future works regarding UAV swarm .

Specific development of autonomous swarms with UAV-to-UAV communication and coordination ability is central to advancing the utility of UAV swarms. Though swarm technology has yet to be practically utilized in commercial applications, there exists great potential. The use of mesh ad-hoc framework alleviates limiting factors for traditional UAV swarm communication approaches.

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