SALVS-01: Specify Animals Location Via Sound (Constellation Mission)

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ABSTRACT

SALVS-01 focuses on wildlife detection using the noise animals make and AI to identify their species and their locations to assist monitoring wild animals with surveillance cameras. The TerraTrack Alerts record the ambient noises in a remote forest, process it, and then send the data to the TerraTrack Hub, which will accumulate all the data gathered from every TerraTrack Alerts and send the data to our satellites, and it will send down the processed mission data to the ground station so that the data can be spread and used. The satellites have 4 modes of operations: firstly if the voltage fall below, 3.5V the satellite would turn idle; the second mode is Normal mode, the telemetry data will be sent out using CW (Continuous Wave); the third mode is Mission mode, the satellites will receive 2 types of data Calling and Mission data; the last mode is Downlink mode, the satellites will send down the data. This mission will be tested on Huai Kha Khaeng wildlife sanctuary in Thailand, and after it is fully developed it will soon be available in other remote areas.

1.INTRODUCTION

1.1. Importance of tracking animals using sound

Nowadays, there are a lot of threats toward the biodiversity and population of wildlife, and to prevent or understand any harmful effects toward animals, there are obligations to know their population and location especially in the isolated area, to preserve and protect the wildlife from the threats of poachers, loggers, and animal traffickers. So, in order to protect wildlife, some means of surveillance and tracking to assert protection are required. Most species of vertebrates use sound to communicate or to locate their herd, since in a dense forest it is challenging to rely on eyesight alone to interpret the surroundings, because of the abundance of obscuring objects, and sound could be used to sense the presence of things behind an obscurement, so this is the most effective way to uphold surveillance in such a difficult area.

In this project, 5 areas of interest in the Huai Kha Khaeng wildlife sanctuary have been chosen, areas of which were believed to be a home of some endangered species. A large part of the wildlife sanctuary is a dense mixed forest, among many more types of habitats (Figure 1-1). Because of its remoteness it is difficult and expensive to track down the location of the endangered species. Traditional means of tracking these animals such as manually implanting tracking device onto the animals and installing surveillance cameras are very cost inefficient and there’s limitation in terms of field of view. These examples pose risks to the forest officers and to the animal itself. So, the method of locating using sound could compensate for the mentioned limitation, also the noise that animals make could help with the understanding of their presence and well-being, whether the animals are healthy or in any danger. Thus, using surveillance cameras along with this project would be extremely efficient. Furthermore, this project deals with the difficulty of remoteness because of the use of satellites as part of the project.

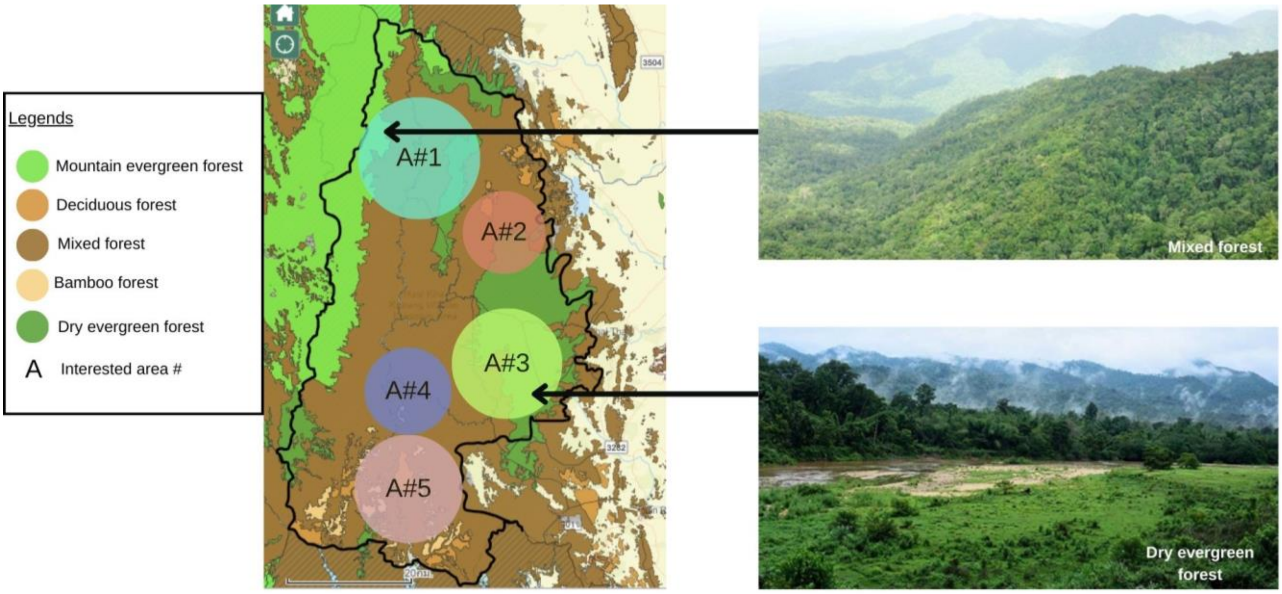
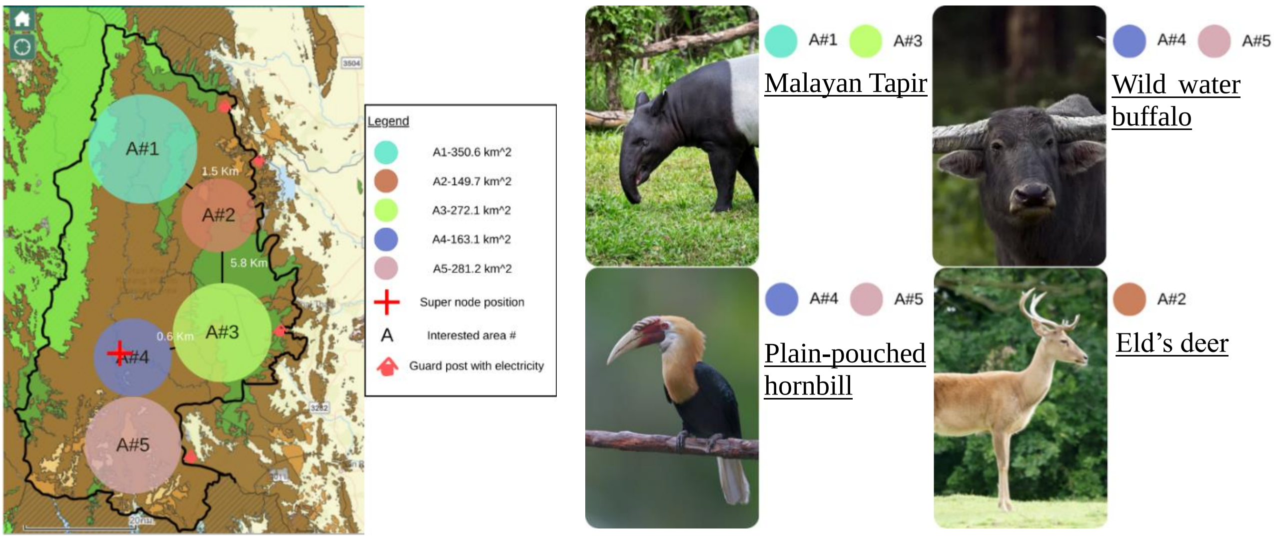


Figure 1-1. Sample areas of Huai Kha Khaeng

2. MISSION OBJECTIVES

SALVS-01 focuses on detecting and observing 4 types of endangered animals in the most remote areas, without electricity or Internet. The areas of interest are in Huai Kha Khaeng Wildlife Sanctuaries, Uthai Thani, Thailand. There are a total of 5 interested areas, with a total area of around 1,217.6 km^2 that varies in elevation, plantations, and food source. The plan is that the TerraTrack Alerts will be installed throughout the areas of interest. The TerraTrack Alert would have a microphone installed, so it could detect the incoming animal sound, and measure the intensity of that sound. For instance, there are 2 TerraTrack Alerts, one is positioned near an animal, another is further away. When the animals make a noise at a certain intensity, the nearest node would sense the highest intensity, the further away TerraTrack Alert would sense a lower intensity. By analyzing these variations in sound intensity, the TerraTrack Alert could estimate the location of the animal using an AI to determine whether the incoming sounds originate from animals of interest (Figure 2-1b) or not. The TerraTrack Alert would store the interested animals' sound and pass it on as mission data every minute, including Start time, ID number of the TerraTrack Alert, animal's species, animal's presences, presence time interval, peak intensity, temperature, and humidity between itself and sends it to the TerraTrack Hub with LoRa. The TerraTrack Hub would collect and accumulate mission data, then send it to the TerraTrack-Sat using UHF band at a frequency range of 435-438 MHz and transmit the mission data down to the ground station to be utilized.



(a) (b)

Figure 2-1. (a) Distances between an area of interest, (b) Animals of interest

3. CONCEPT OF OPERATIONS

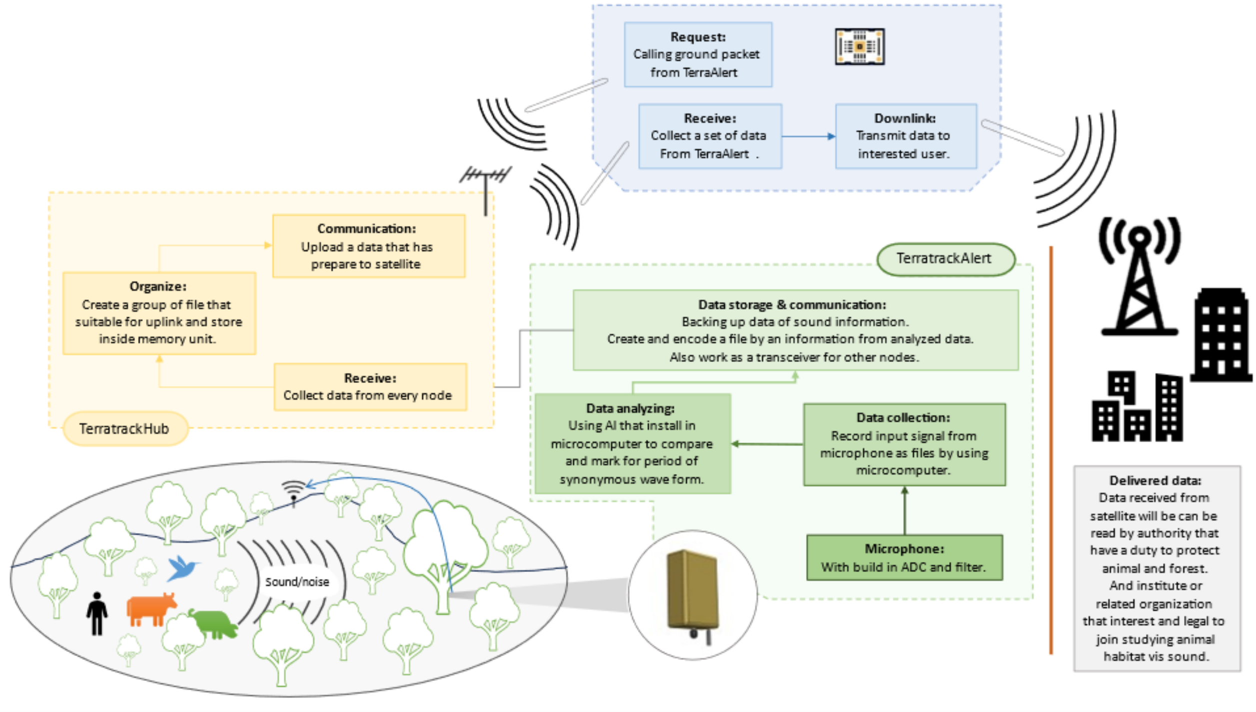


Figure 3-1. CONOPS of ground segment

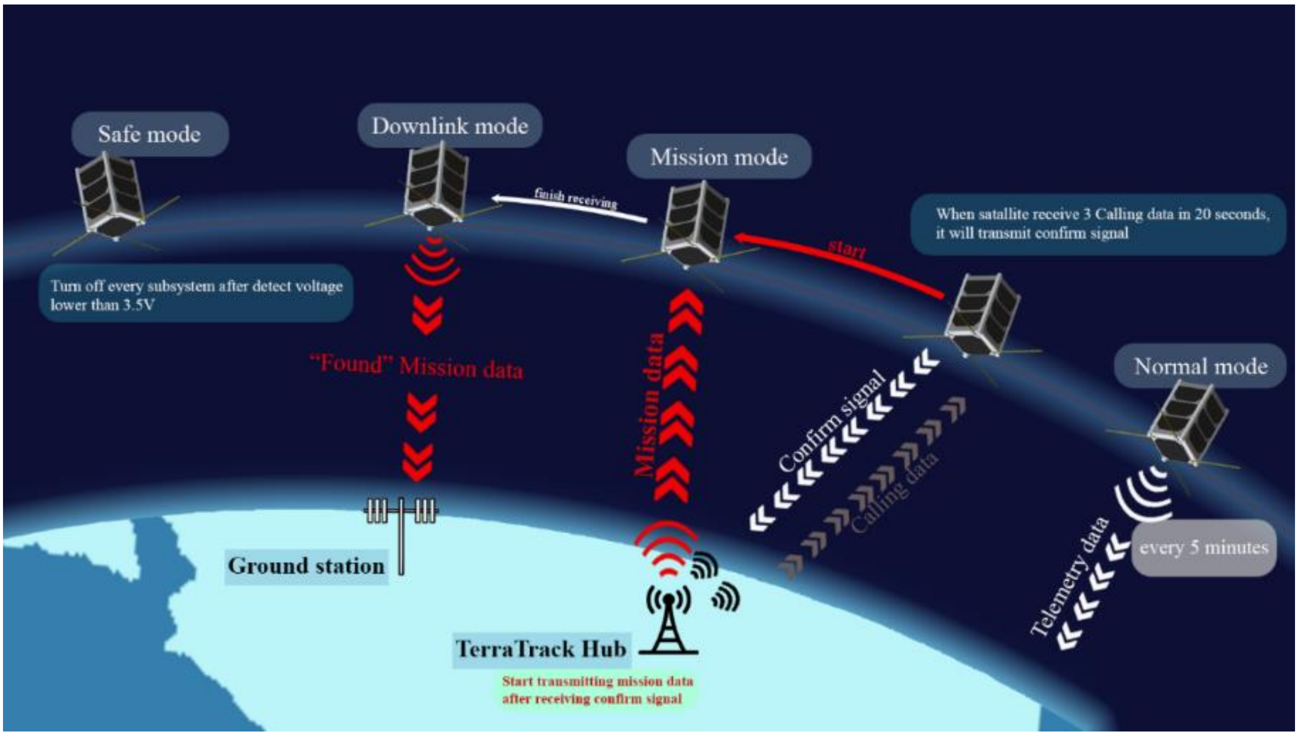


Figure 3-2. CONOPS of space segment

4. KEY PERFORMANCE PARAMETERS

Ground segment

1. Precision of the Artificial Intelligence
2. F1-score
3. Recall
4. Accuracy Percentage
5. Number of Correct
6. Range of Communication and detection

Space segment

1. TerraTrack-Sat should be able to receive mission data within 300 seconds.
2. TerraTrack-Sat average energy usage lower than 2000 mWh per shaded orbit time.

For each key performance parameter of the ground segment, if one model performs better than another, it will receive an additional score of 1 point. At the end, all the scores will be collected and compared. Then, the model with the highest score will be selected for usage. For the range of communication and detection, communication range should be at least 200 m, and detection range should be at least 20 m without any extension and interference noises.

Model	Precision	Recall	F1-Score	Number of Correct Classifications	Accuracy Percentage	Summation of Scores
Model 1	0.818182	0.6	0.692308	90	0.64516129	5
Model 2	0.285714	0.352941	0.315789	50	0.322580645	0

Table 4-1. Example of an expectation of AI model comparison score

SF	Chirps / Symbol	SNR	Airtime [a]	Bitrate
7	128	−7.5	56.5 ms	5469 bps
8	256	−10	−103 ms	3125 bps
9	512	−12.5	185.3 ms	1758 bps
10	1024	−15	371 ms	977 bps
11	2048	−17.5	741 ms	537 bps
12	4096	−20	1318.9 ms	293 bps

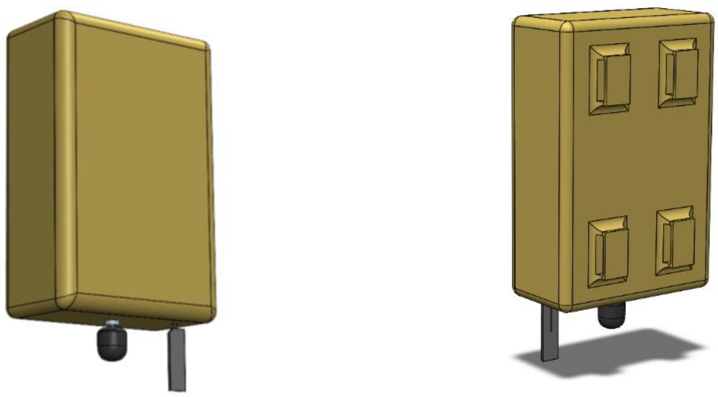
[a] 20 bytes per packet and Code Rate = 4/5.

Table 4-2. Communication parameters

5. GROUND SEGMENT DESCRIPTION

5.1. TerraTrack Alert

As shown in Figure 5-1, the TerraTrack Alert primary design philosophy of this instrument focused mainly on durability, light weight, and self-sustainability. This instrument consists of a Raspberry Pi 4, an Omni-directional Mic. AS-0, an SD card, a Flexible PCB antenna, a Semtech SX1262, a TP 4056 (battery charger), and 3 of 18650 Li-ion battery pack 5V 2200mAh connected in parallel. (This design needs further test in real environment.)



(a) (b)

Figure 5-1. (a) TerraTrack Alert front side, (b) TerraTrack Alert back side

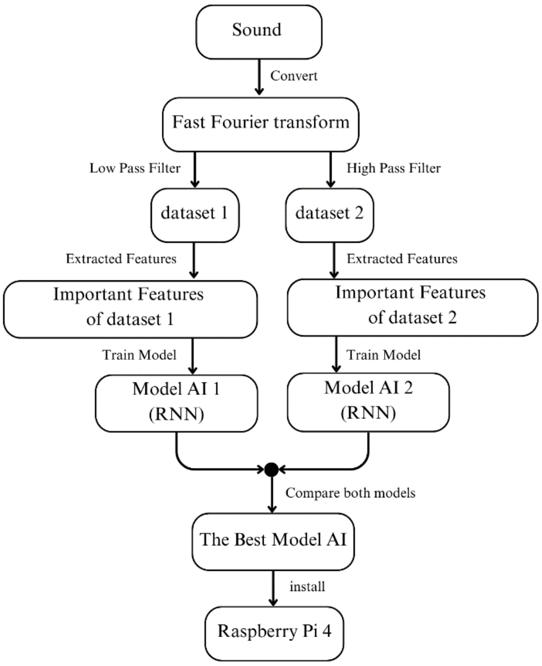


Figure 5-2. AI noise analyzing training process diagram.

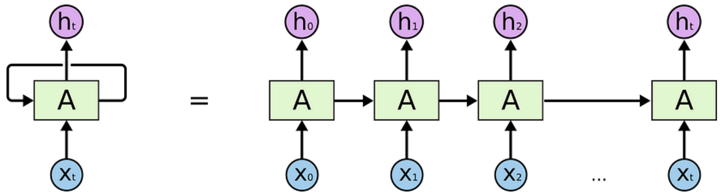


Figure 5-3. Process of Recurrent Neural Network (RNN)

5.1.1. AI procedure training (Figure 5-2.)

Firstly, a fast Fourier transform will be applied. The signal will be filtered using both Low Pass and High Pass filters, resulting in two types of sound data. Therefore, the specific frequency range associated with the animals was separated, thereby enhancing precision in the analysis. Then important features such as frequency minima and similar frequency patterns will be extracted from both sets of sound data. Subsequently, both sets of sound data will be used to train an AI model. Once the AI model training is completed, its performance will be evaluated to determine which AI model performs better in sound classification. This process will be repeated until all animal sounds have been identified. Finally, the most efficient AI model will be installed on a Raspberry Pi 4 connected to a microphone for the purpose of capturing and classifying various animal sounds, as well as recording encountered animal data.

5.1.2. Filter procedure of the AI (Figure 5-3.)

Identifying animal sounds is quite difficult due to the different nature of vocal structures and communication variation. Thus, we will develop an Artificial Intelligence model by using Recurrent Neural Network (RNN) deep learning to address this issue. A Recurrent Neural Network (RNN) is a type of deep learning model which combines and processes its output, that came from hidden state, and current hidden state. The model will simultaneously work in loops and creates an AI model at the end of the process. With this operating process, it’s suitable for audio data which is considered a type of time series data.

5.1.3. TerraTrack Alerts determination of nodes number

The determination of the number of nodes in Figure 5-4 was done by employing the ARRAYPATH command to calculate and display the positions of nodes along the specified path, making our work smoother and more accurate without the needs of a complicated calculation method.

The microphones installed on the TerraTrack Alert can detect whether there are animals nearby or not, and send the data to the others TerraTrack Alert. Therefore, the TerraTrack Alerts would know where the animal is located in real time.

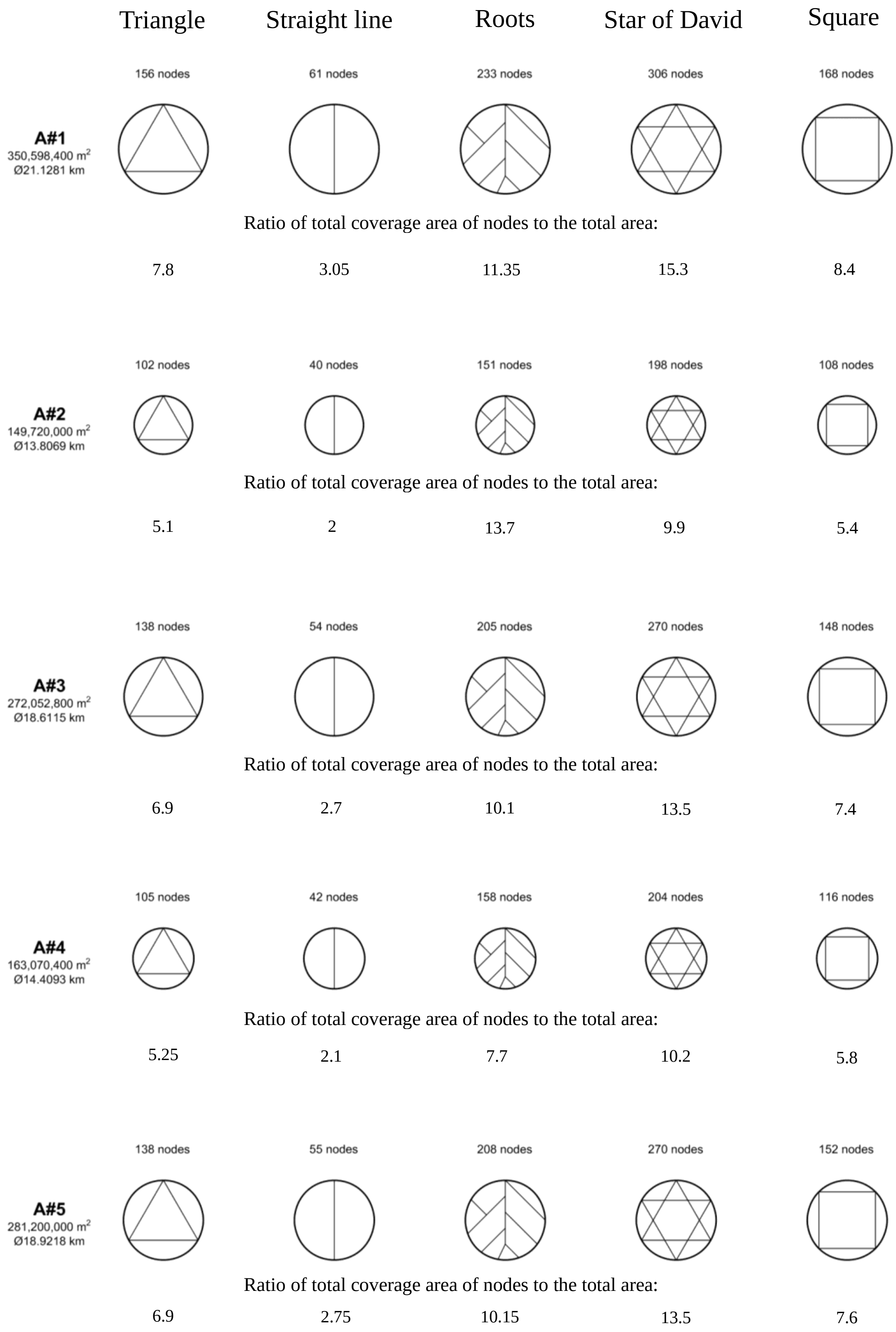


Figure 5-4. TerraTrack Alert network pattern

5.1.4. Communication

To Gather data across 5 interest areas, there are 5 patterns of the TerraTrack Alerts placement formation. The Roots formation was selected from comparing the ratio of the total area of interest to the total coverage area of the TerraTrack Alert, each TerraTrack Alerts will be place separately with a distance by about 200 m. The algorithm Breadth – First – Search is applied to pass on the data from TerraTrack Alerts to The TerraTrack Hub in the shortest path possible.

5.2. TerraTrack Hub

Determining the optimal location for a TerraTrack Hub installation prioritizes three key factors in order of importance:

5.2.1. Communication coverage - The TerraTrack Alerts are placed in 5 areas, and in each area, there must be sufficient numbers of TerraTrack Alerts and at the right locations, so that the TerraTrack Hub can fully receive data from all the TerraTrack Alerts of all the areas.

5.2.2. Environment conditions - The completeness of signal transmission depends on both the forest's types and density. In a densely packed forest with tall trees, signal transmission may be hindered.

5.2.3. Power availability - Some guard posts in the Huai Kha Khaeng Wildlife Sanctuary have an electric generator that could produce 1500 watts of electrical power. Therefore, if that spot is convenient for the placement of a TerraTrack Hub, the difficulty of building a source of electricity will be alleviated.

6. SPACE SEGMENT DESCRIPTION

6.1. Satellite operation mode (Figure 3-2. CONOPS of space segment)

6.1.1. Normal mode - This mode will activate while TerraTrack-Sat is in orbit, transmitting Telemetry Data by Continuous Wave (CW) Beacon every 5 minutes.

6.1.2. Mission mode - This mode will be activated when TerraTrack-Sat passes over Ground station and receives one of two data types, Calling and Mission data. It would receive 3 Calling data every 20 seconds to know which satellites receive the data out of the seven others are at the best position, and it will transmit confirmation signal to the Ground station to start transmitting Mission data, ending after receiving all the mission data.

6.1.3. Downlink mode - TerraTrack-Sat will transmit SALVS data (recorded mission data) to the Ground station. This mode starts after the mission mode.

6.1.4. Safe mode - In this mode, TerraTrack-Sat will turn-off every subsystem if the detected voltage is lower than 3.5V.

Components	Model name
Structure	AL-A7075-T6
MCU	STM32F401
communication	DP-CRF-5549
Battery	UBP103450/PCM
ADCS	
-Current driver	TB6612FNG
-Magnitometer , gyroscope	LODESTONE
-Sun sensor	S3931
Sensor	
-GPS	k500
-Temperature	LM335A
CD&H	
-RTC	DS1307
-i2cmutiplexer	PCA9548A
-Memory eeprom	24LC256
-Memory fram	MB85RC1MT

Table 6. Components table

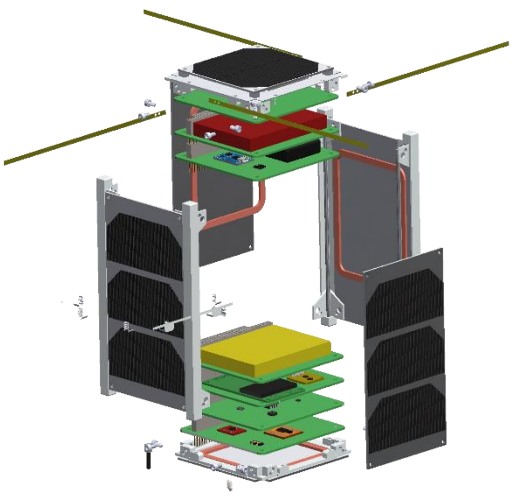


Figure 6-1. 3D CAD of TerraTrack-Sat

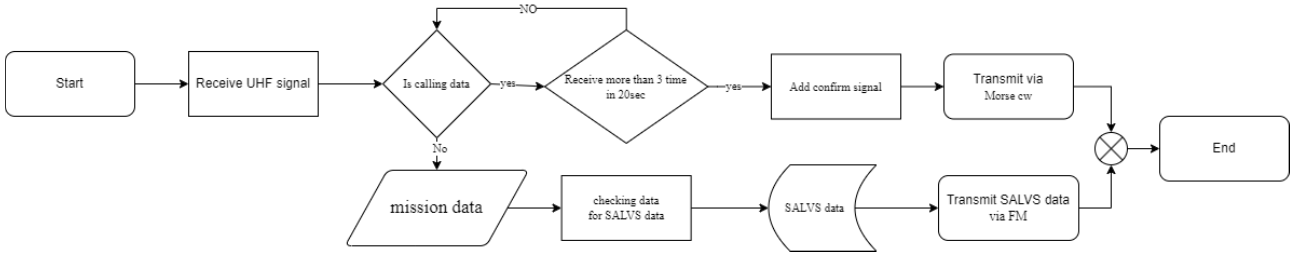


Figure 6-2. Communication flowchart

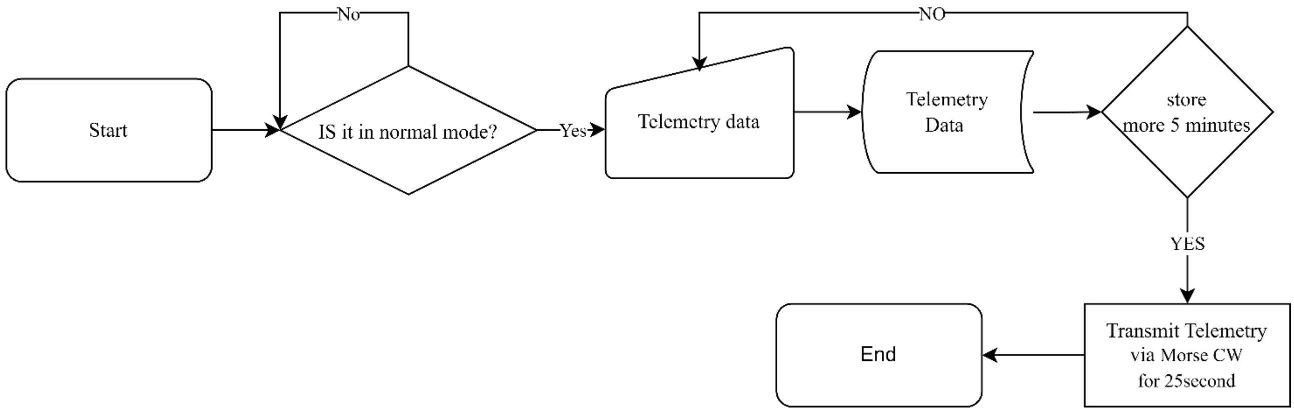


Figure 6-3. Telemetry data flowchart

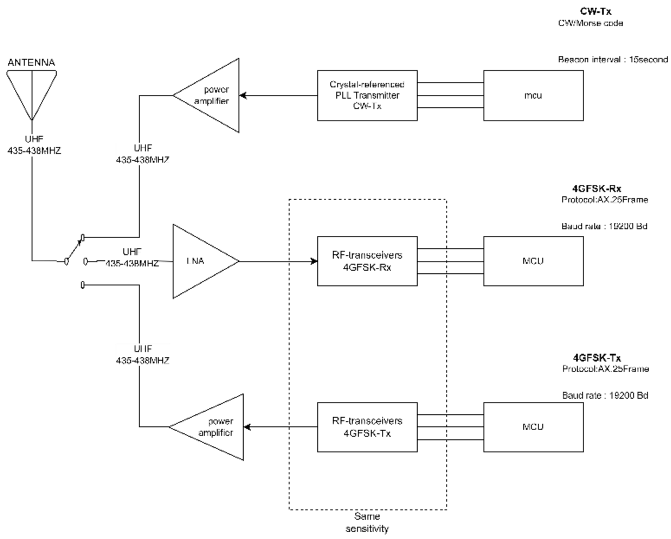


Figure 6-4. Communication hardware diagram

6.2. Satellites Subsystem

6.2.1. Communication Subsystem - The TerraTrack-Sat constellation was designed to use an Omnidirectional Antenna with the same frequency range throughout the constellation, by using an UHF Band 435-438 MHZ for both Receive-data and Transmit data (mission data), as shown in Figure 6-4. The receive data includes calling data and mission data. The calling data is an uplink Morse CW in Mission mode. The mission data is the data from the Ground segment in AX.25 protocol with 4-GFSK modulation. The estimated received time was about 278.86 seconds which included 1 MB of data with a baud rate of 38,400 bytes per second, that contained Mission data (detect time, animal types, sound intensity, temp., HMD). Morse and FM are used by the TerraTrack-Sat to transmit data. Morse is CW in OOK modulation, Morse is compact Telemetry-data or Confirm Calling signal. Telemetry data will be transmitted every 5 minutes interval for 25 seconds, as in Figure 6-3. The Confirm Calling signal transmits during mission mode for commanding the ground station to transmit the mission data. FM is SALVS data. SALVS data are comprised of Found's mission data and was transmitted by AX.25 protocol with 4-GFSK modulation to the ground station. The maximum time taken to transmit the data is estimated to be about 278.86 seconds, thus TerraTrack-Sat can complete the mission within one orbital pass.

6.2.2. Attitude Determination and Control System - TerraTrack-Sat uses a Permanent Magnet mechanism to align itself with Earth's magnetic field, since the mission does not require a precise viewing angle and has low available power.

6.2.3. On-Board Computer - STM32F401 is selected due to its low operating Current, low Voltage usage along with Self-Timer, Temperature sensor, high-capacity Flash Memory, and large RAM. All of these harmonize with TerraTrack-Sat mission.

6.2.4. Electrical Power System - Shown down below are the TerraTrack-Sat power consumption table (Table 6-1) and active time of each mode (Table 6-2). TerraTrack-Sat is estimated to on average consume power of 778.48 mW in sunlight and in escape consumes 278.96 mW. TerraTrack-Sat is designed to generate power with Gallium Arsenide (GaAs) solar panel. XY panel contains 4 solar panels that gives an output of approximately 6.0V. Power generated from solar panels at BOL is 3600 mWh, and at EOL 29% of said value will be left (1044 mWh). The required battery capacity is 1145.61 mAh, assuming 10% DOD with a 20% margin. The TerraTrack-Sat energy balance is calculated as seen in TerraTrack-Sat Energy balance table (Table 6-3). The balance is positive, generating energy of 1264.56 mWh per orbit.

mode / Subsystem	Normal mode CW Tx	Normal mode NO CW Tx	Mission mode Rx	Mission mode CW Tx	Downlink mode	Safe mode
Communication	1362.9	82.5	108.075	1362.9	2640	82.5
ADCS	255	0	255	255	255	0
EPS	150	150	150	150	150	150
CDH	103.56	107.47	107.47	103.56	103.56	93.63
Payload OBC	36.72	36.72	36.72	36.72	36.72	7.56
Total (mW)	1871.46	339.97	620.55	1871.46	3148.56	243.83

Table 6-1. TerraTrack-Sat power consumption

Modes	Active time (minutes)
Normal mode	85.005
Mission mode	4.5976
Downlink mode	4.5976
Safe mode	TBD

Table 6-2. Modes active time

Energy	Energy Consumed (mWh)
Average Gained	2322
Use	-1057.44
Balance	1264.56

Table 6-3. TerraTrack-Sat Energy balance

Altitude (km)	500	Downlink →	Final Margin (dB)	5.593
Temp (K)	371.535	Uplink →	Final Margin (dB)	3.131

Table 6-4. Link Budget

7. ORBIT/CONSTELLATION DESCRIPTION

To ensure TerraTrack-Sat orbit's footprint is accurate, GLAST[18] is set as the reference footprint. TerraTrack-Sat constellation will launch a group of eight satellites into Low Earth Orbit (LEO), an orbital region relatively close to Earth, at altitudes of 500 km. This will give each one an orbital period of 1 hour, 34 minutes, and 36 seconds. With each satellite positioned about 45 degrees apart from one another in terms of right ascension of the ascending node, the constellation will reliably cover the Area of interest in Huai Kha Khaeng, but a delay in operation schedule for each satellite is to be expected, due to the possibility of rocket shortage. Based on a simulation for September 2023, the complete constellation will pass by 469 times per month, and the Ground visibility time will be more than 8 minutes each time it passes by.

TerraTrack-Sat	01	02	03	04	05	06	07	08
a (km)	6858	6858	6858	6858	6858	6858	6858	6858
e	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
i (°)	25	25	25	25	25	25	25	25
ω (°)	75	75	75	75	75	75	75	75
Ω (°)	0	45	90	135	180	225	270	315
M (°)	100	100	100	100	100	100	100	100

Table 7. Orbit elements

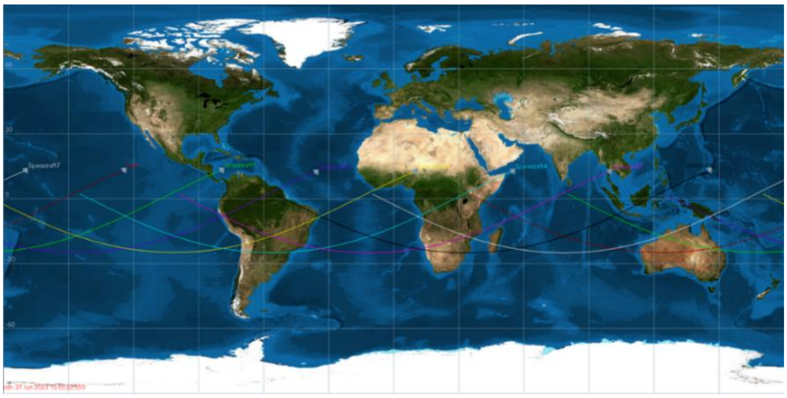


Figure 7-1. TerraTrack-Sat orbital trajectory

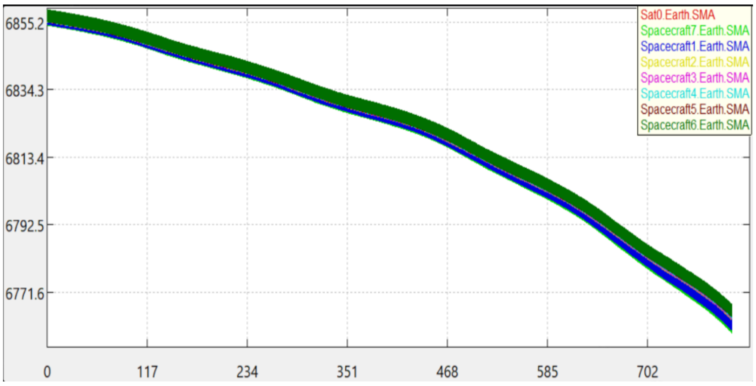


Figure 7-2. Orbital simulation

Low Earth Orbit (LEO) was chosen for the TerraTrack-Sat because it serves the mission's goals effectively. It allows the satellites to maintain stable communication using minimal power. Plus, it's more cost-effective compared to the pricier option of placing satellites in Geostationary Orbits (GEO). This approach will help the satellites maintain constant coverage over targeted areas and expand the reach to protect essential forests globally, all while keeping efficiency and affordability in mind.

8. IMPLEMENTATION PLAN

When the ground segment is fully developed, our team would like to see this project in other remote areas around the globe, e.g., in South America, Africa, etc., since the satellites are already on standby in orbit.

8.1 Ground segment

The ground system must consider the hazards in the form of physical, chemical and radiation ones, that could be inflicted to the local nature as the first priority. The component of each node will be ordered from a different company and assembled inside a clean room to reduce contamination and human smell on the node, so animals won't get scared of the nodes, and will be more likely to go near the nodes. For all 1000 nodes, the cost for the ground system is approximately $1,500,000. To install a ground system inside Huai Kha Khaeng, Thailand's

Department of National Park, Wildlife and Plant Conservation's permission are required. Afterward, the installation of each node needs to be done by humans and the node container will be installed 4.5 meters from the ground to avoid damage from elephants and other large animals. Also, the solar panel will be placed on top of the chosen tree then wired down into the container. To test the ground system will involve 3 teams to standby at each area, and another team is at the TerraTrack Hub.

8.2 Space segment

The estimated mission lifespan of the constellation is 2.5 years: after this period, the orbits will decay and re-enter Earth's atmosphere. Our plan is to send more constellation to carry on the project by sending 1 satellite per launch (the cost of launching 8 satellites in 1 launch is the same as 8 launches), but there will be some difficulties in finding launch vehicle, the extent of collaboration with the Department of National Parks Wildlife and Plants, and the advancements in future camera detection technology. Most of the components required for TerraTrack-Sat are readily available on the market, with an estimated cost of approximately $70,000 USD per TerraTrack-Sat through EnduroSat. Alternatively, we can consider a custom-built approach by students, which may take more time but offers the opportunity for students involved in the project to learn, develop their skills, and potentially reduce costs compared to the initial estimate. We are actively collaborating with Thailand's Department of National Parks, Wildlife, and Plant Conservation to obtain the necessary permissions for installing TerraTrack Alerts and Hub systems. The information obtained through this collaboration will be shared and used to enhance our methods for studying endangered species. Our ground station is expected to be in Bangkok, Thailand, to facilitate easy operations and communication with the constellation.

8.3 Risks Management

possibility \ impact	negligible	intermediate	critical
Moderate		Antenna displacement	Insufficient data storage
Intermediate	The performance measurement for AI Classification	Other animal noise interference	Power shortage
Immense	Ambient noise interference	Instrument falling off the placement	Natural direct disturbance ex. A Storm, animal pushing the instrument off the placement, etc.

Table 8-1. Possible Risks

Risks	**Countermeasures**
Antenna shift off its original placement	Adjust and tighten the antenna position
The performance measurement for AI classification	Increase the training cycle for our AI, add more training models, increase amount of data for AI training
Ambient noise interference	Using our filter to filter out other noises
Other animal noise interference	Using our filter to filter out other noises
Instrument falling off the placement	Tighten the placement
Insufficient data storage	Compress data, and clear cache data
Power shortage	Change to more efficient circuit
Natural direct disturbance	Test the durability of our instruments in a simulated environment

Table 8-2. Risks and Countermeasures

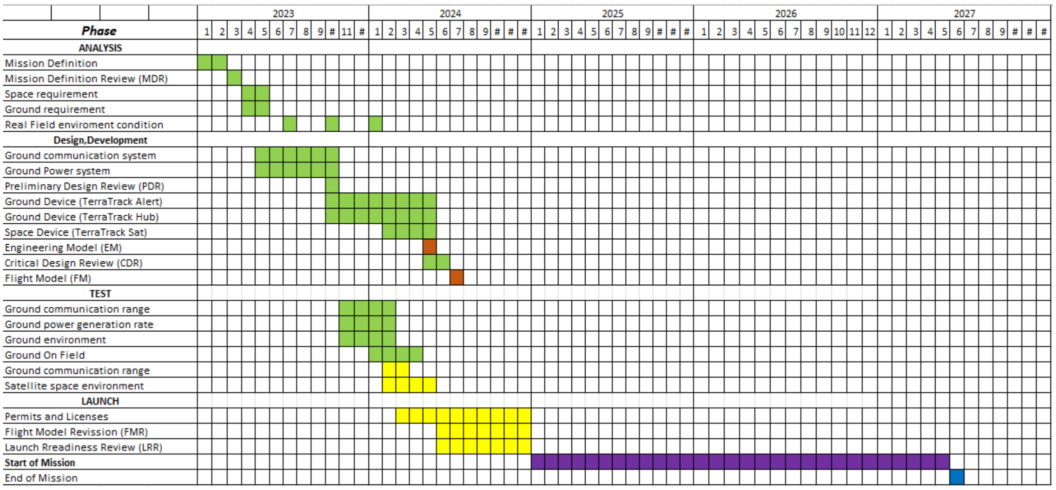


Table 8-3. Project Schedule

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