Border Security: Air Team

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Abstract

It was the goal of the Air team to come up with a network of UAVs that could patrol the US-Mexico border with efficiency, while remaining cost effective. The purpose for the Air team was one of detection of intruders as opposed to detainment. One major constraint from the outset was that the UAVs were to be “off the shelf” technology. For this reason, UAVs in the testing phase were not considered. Several initial requirements were set up that put constraints on the endurance and range of the UAVs. There were also requirements on sensors and communication equipment that ensured proper detection and communication under all environmental conditions.

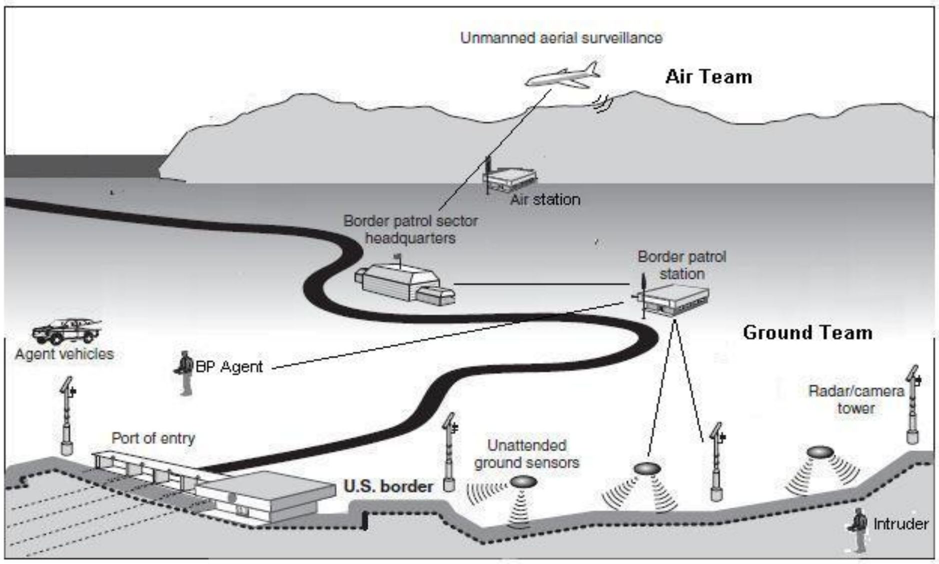


Figure 1: Border Security System

The above picture shows the Border Security System as a whole, including both air and ground assets. The Air and Ground teams worked together to provide a system that has a comprehensive picture of the border while remaining cost effective. The UAV will remain in constant communication with the ground base to effectively detect and track targets. After much deliberation and trade-off analysis, the Predator 1-C was chosen as the UAV to patrol the US-Mexico border as it offered superior coverage and a very low cost.

1. Problem Statement

1.1 Why is this border security system needed?

The US-Mexico border is currently a hot political topic. The border is not entirely secure and is open to threats of various kinds. With an unsecure border, the US opens itself to terrorist attacks and extensive drug running and other forms of smuggling. In addition to these problems, there is also the large influx of illegal aliens. It is estimated that there are 500,000 illegal entries each year.

1.2 Previous Solution Attempts

The most recent attempted solution was Boeing's SBInet in 2006. Boeing's system was going to cover both of the US' borders, Canada and Mexico, a total range of 6,000 miles. They would employ a tower system consisting of 1800 towers, with both sensors and/or border agents, command centers, Border Patrol Agents with GPS devices and UAVs. They built a pilot section in Arizona that spanned 28 miles and cost $67 million. The estimated cost of completion was between 2 and 8 billion. In January 2011, the program was canceled due to both cost overruns and lack of effectiveness.

1.3 Description of Border

The US-Mexico border has a wide variety of terrain. It spans almost 2000 miles and has many different geographical features including deserts, mountains, rivers and cities. Temperatures also vary greatly, from 32 to 113 degrees Fahrenheit.

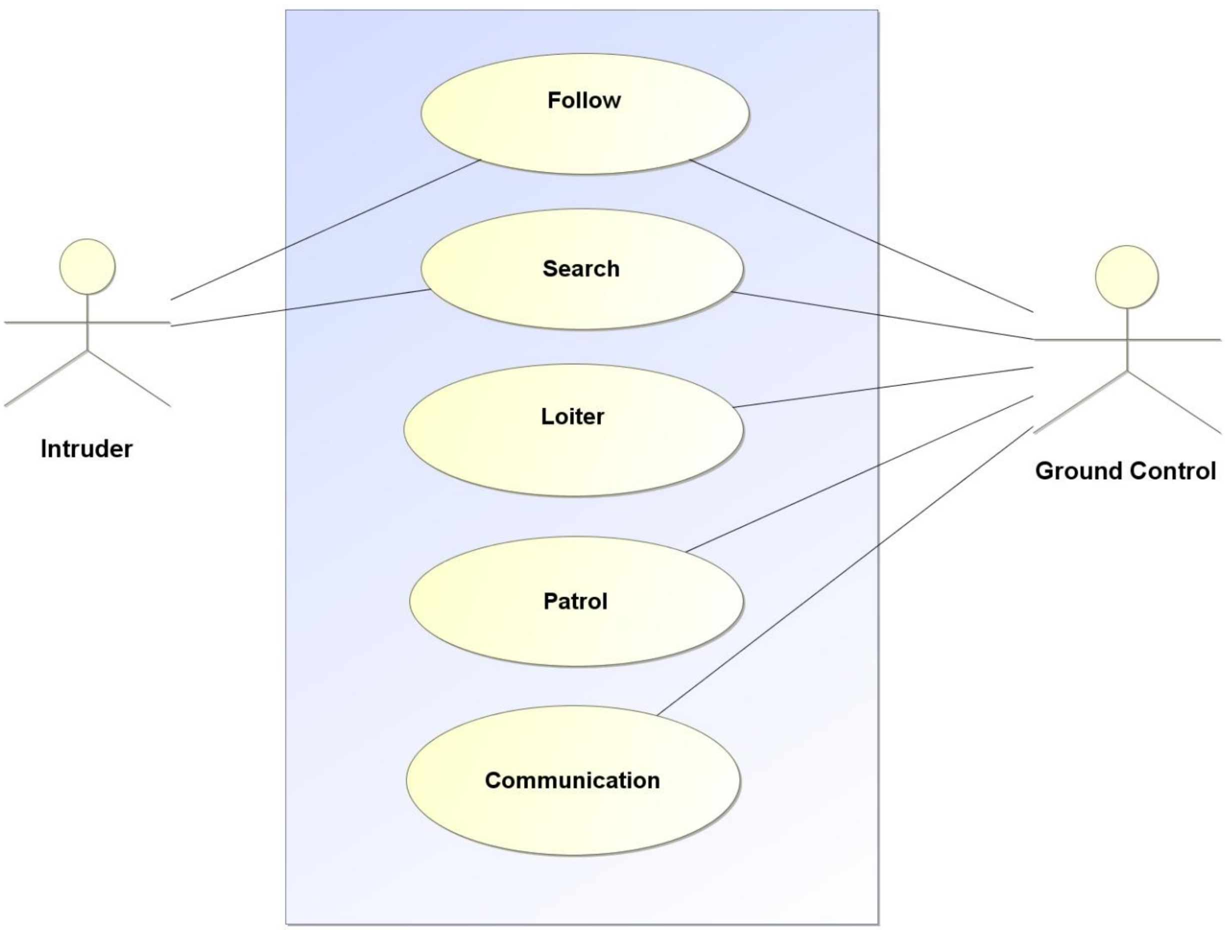
Figure 2: US-Mexico Border

1.4 Potential Implications of Solution

- Decreased influx of illegal aliens
- Less drugs entering the US
- Potential to allocate funds from current border patrol to other things
- US less susceptible to terrorists entering from the US-Mexico border

2. Use Cases

2.1 Use Case Diagram



2.2 Textual Scenarios and Activity Diagrams

UAV Patrol Case:

Primary Actor(s): Ground Base

Description: UAV executes pre-programed flight path for given area of surveillance.

Preconditions: UAV has determined flight path, is in flight and no intrusion detected.

Flow of Events:

1. Current flight status downlinked to ground base.
2. Sensors set to patrol mode.
3. Execute flight path.
4. Communicate to ground base.
5. UAV detects intrusion.
6. Communicates information to ground base.
7. UAV waits for target verification from ground base.

Alternate Flow of Events

1. UAV encounters error or flight problem (i.e. low fuel, sensor malfunction, etc.)
2. UAV sends warning to ground base
3. Ground base launches second UAV to execute mission
4. Initial UAV that has encountered an error lands

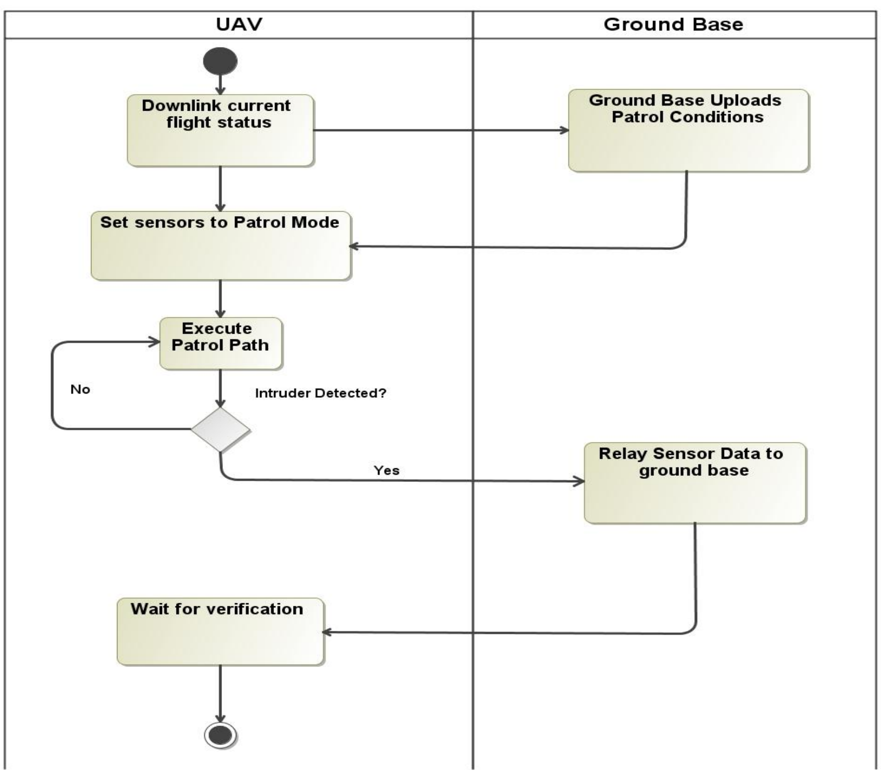


Figure 3: Activity diagram for patrol use case

<u>UAV Loiter Case:</u>
Primary Actor(s): Ground Base
Descriiption: UAV Holds position over pre determined location of interest.
Preconditions: UAV is in flight
Flow of Events:

1. Downlink current UAV status
2. Ground base uploads loiter conditions
3. Sensors set to loiter mode
4. UAV executes loiter conditions
5. Communicate with ground base
6. UAV detects intrusion.
7. Communicates information to ground base.
8. UAV waits for target verification from ground base.

Alternate Flow of Events

1. UAV encounters error or flight problem (i.e. low fuel, sensor malfunction, etc.)
2. UAV sends warning to ground base
3. Ground base launches second UAV to execute mission
4. Initial UAV that has encountered an error lands

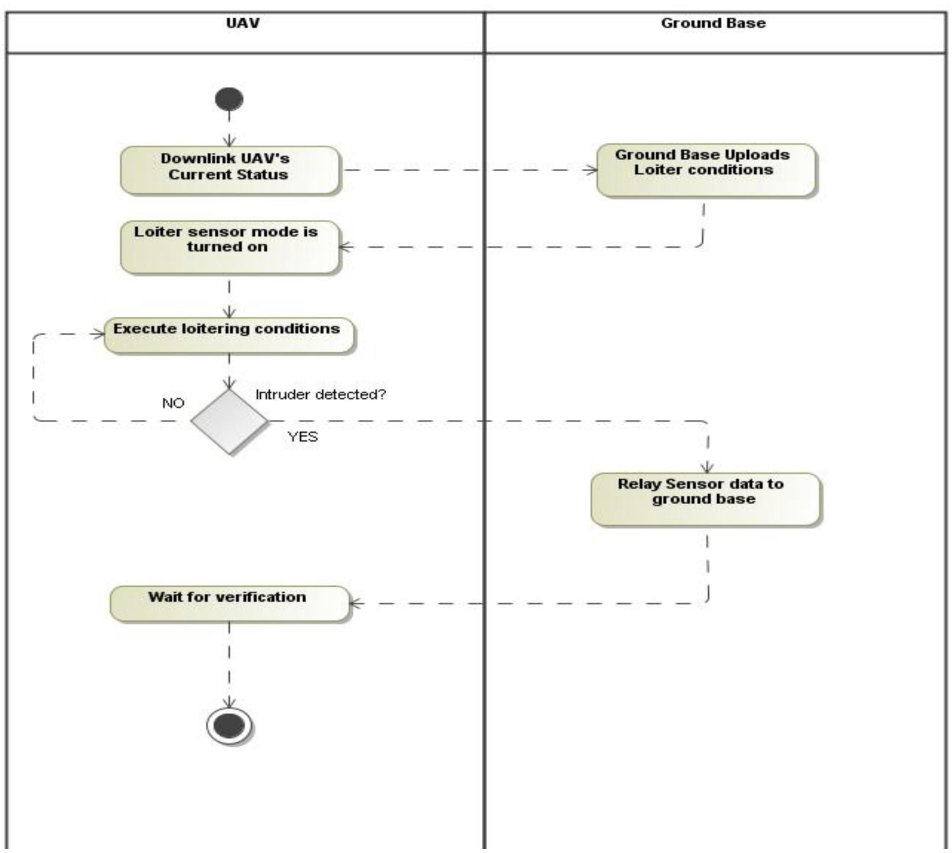


Figure 4: Activity diagram for loiter use case

<u>UAV Search Case:</u>

Primary Actor(s): Ground Base, Intruder

Description: Ground Base reports a detected target to UAV. UAV reports to search location and begins search.

Preconditions: UAV in flight; target on ground detected.

Flow of events:

1. Interrupt issued to UAV from ground base.
2. UAV downlinks current status.
3. Ground base uplinks intrusion locations and area to loiter in search mode.
4. UAV flies to target area to execute search mode.
5. Sensors set to search mode.
6. Communicate with ground base.
7. UAV detects intruder(s).
8. Communicates information to ground base.
9. UAV waits for target verification from ground base.

Alternate Flow of Events

1. UAV encounters error or flight problem (i.e. low fuel, sensor malfunction, etc.)
2. UAV sends warning to ground base
3. Ground base launches second UAV to execute mission
4. Initial UAV that has encountered an error lands

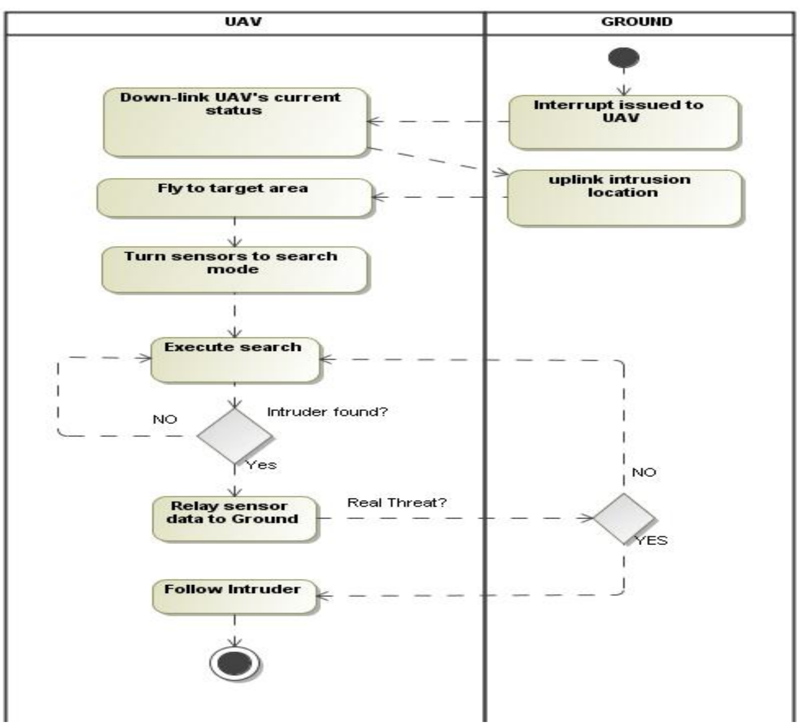


Figure 5: Activity diagram for search use case

UAV Follow Target:
Primary Actor(s): intruder, ground base.
Description: UAV has been given target verification and UAV monitors intruder while constantly communicating targets position to ground base.
Preconditions: UAV is flying. UAV has detected a verified target.
Flow of Events:

1. UAV loiters around dynamic location of target.
2. UAV downlinks real time information on targets position and velocity.

Alternate Flow of Events

1. UAV encounters error or flight problem (i.e. low fuel, sensor malfunction, etc.)
2. UAV sends warning to ground base
3. Ground base launches second UAV to execute mission
4. Initial UAV that has encountered an error lands

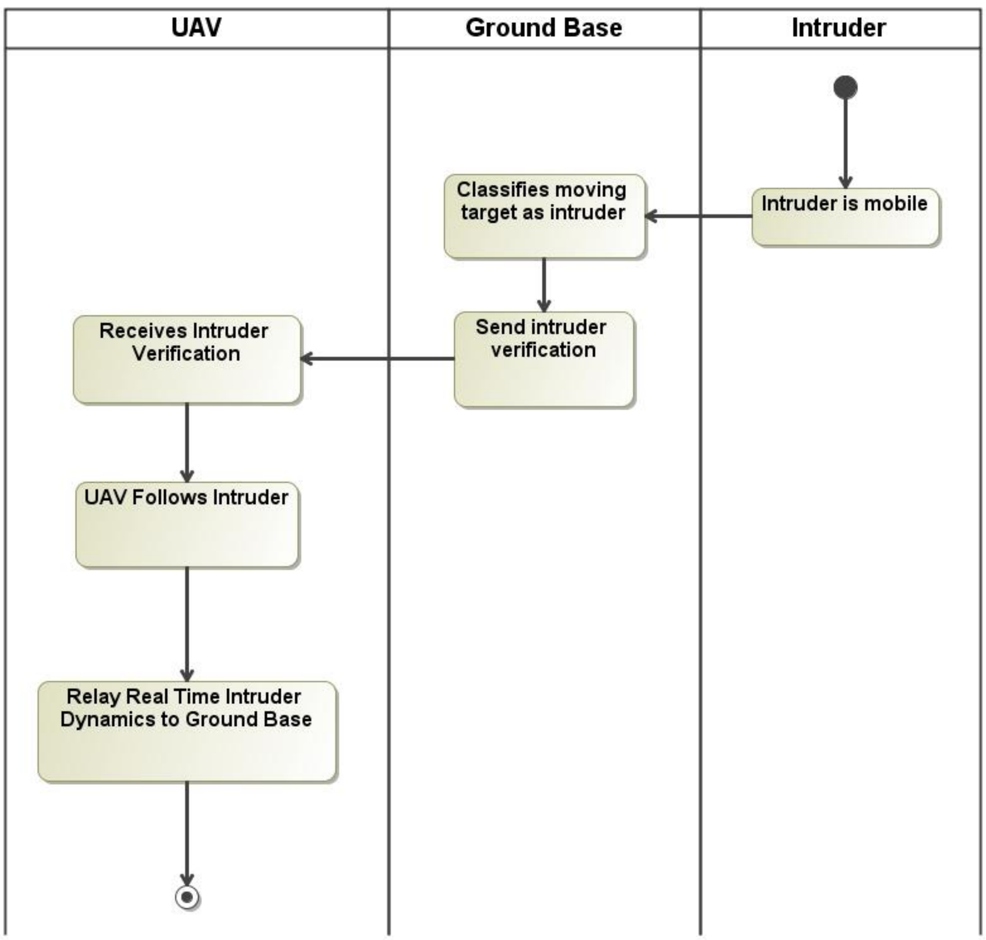


Figure 6: Activity diagram for follow target use case

<u>UAV Communication:</u>

Primary Actor(s): UAV, Ground Base

Description: UAV communicates with ground base to exchange information.

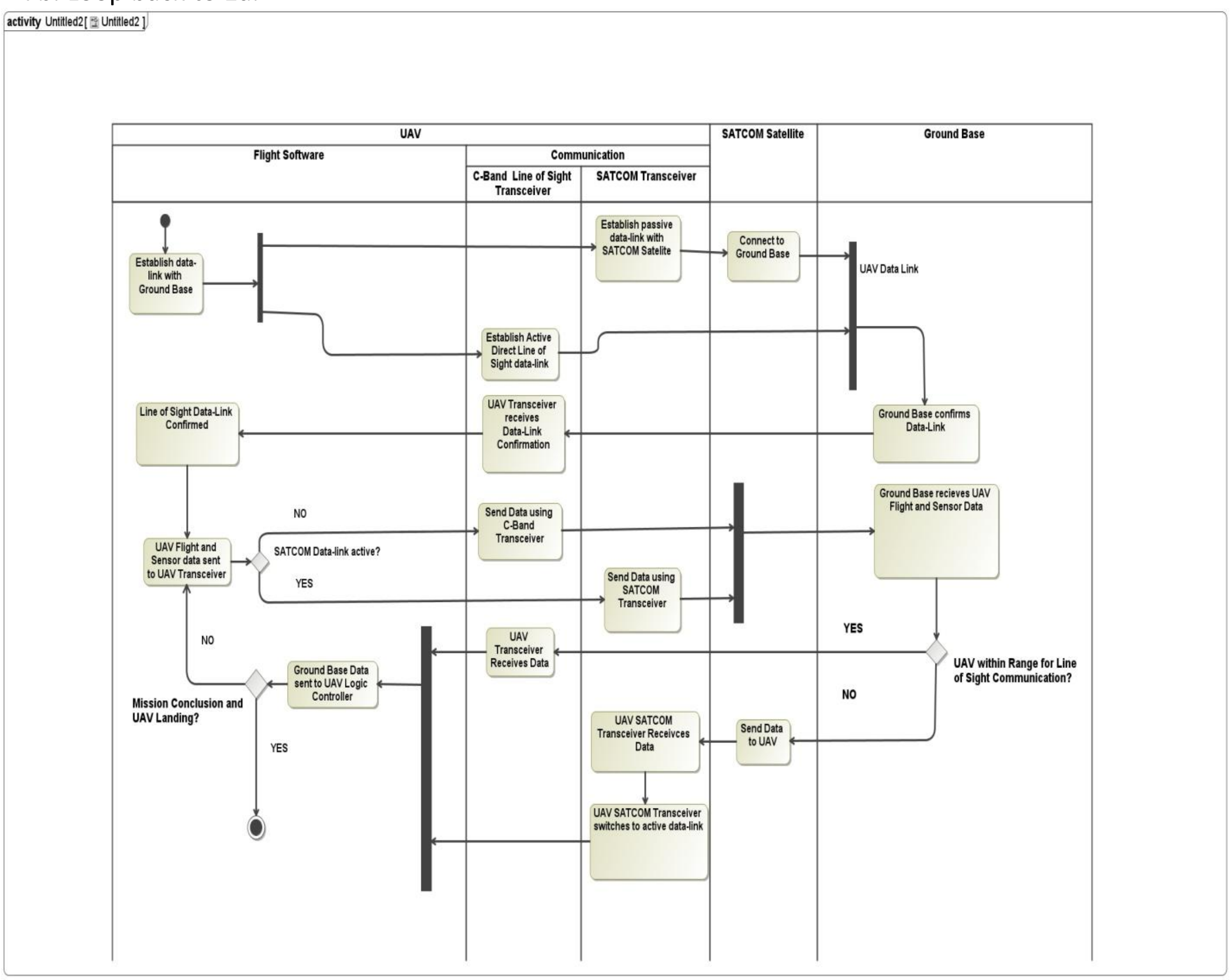
Preconditions: UAV is in flight. Transceiver operational.

Flow of Events:

1a. Data sent to UAV's transceiver
2a. Transceiver attempts to establish direct connection with Ground Base.
3a. Direct connection establish with ground base.
4a. Begins down-link of data to Ground Base.
5a. Transceiver receives data from Ground Base.
6a. Received data sent to UAV's logic controller.
5a. Loops back to 1a.

Alternate Flow of Events #1

1b. Data sent to UAV's transceiver
2b. Transceiver attempts to establish direct connection with Ground Base.
3b. Transceiver fails to establish direct connection with Ground Base.
4b. Transceiver sends data indirectly via SATCOM satellite to Ground Base.
5b. Transceiver receives data indirectly via SATCOM satellite from Ground Base.
6b. Received data sent to UAV's logic controller.
7b. Loop back to 1a.



3. System Behavior

3.1 Sequence Diagrams

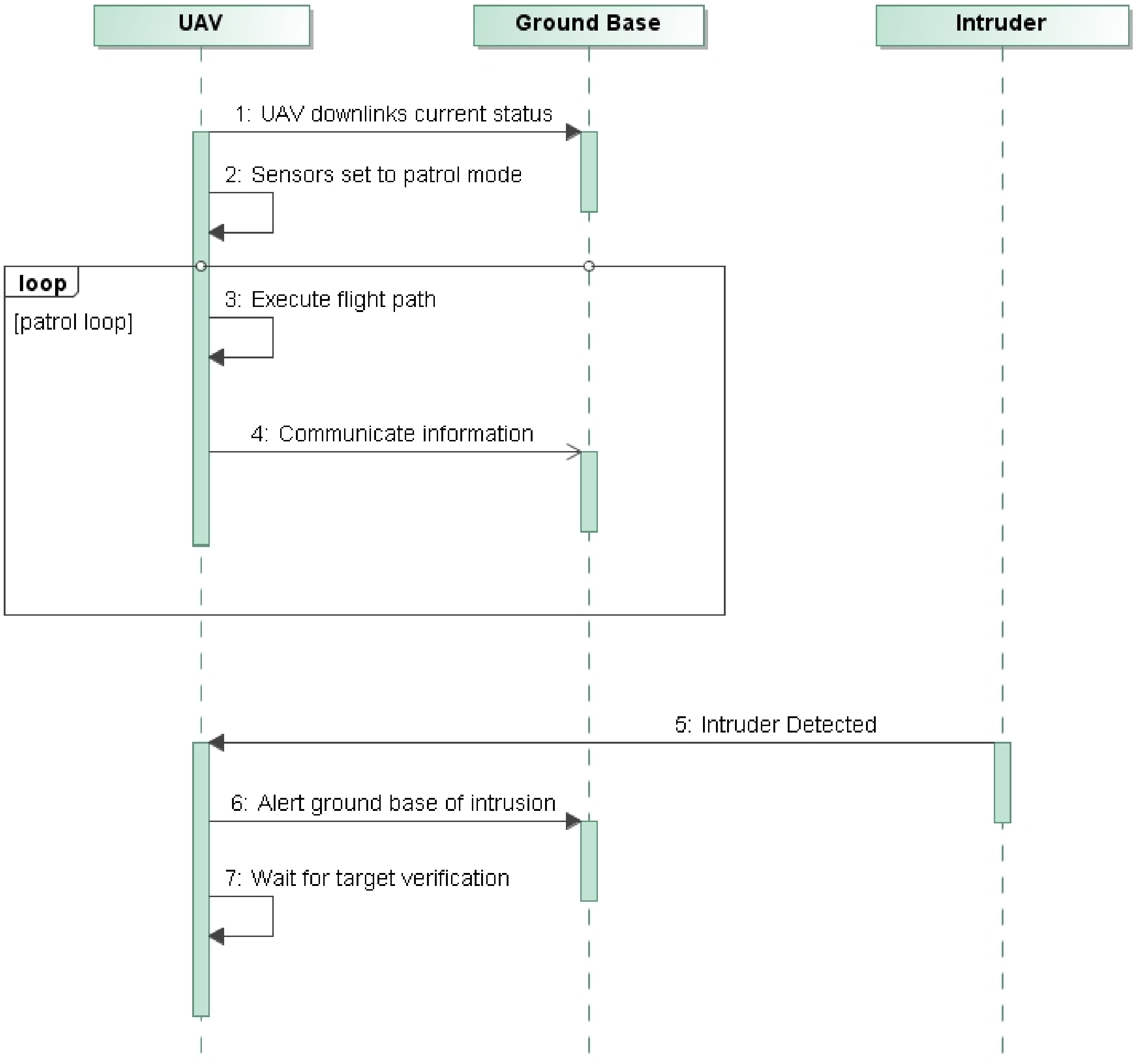


Figure 7: Patrol Sequence Diagram

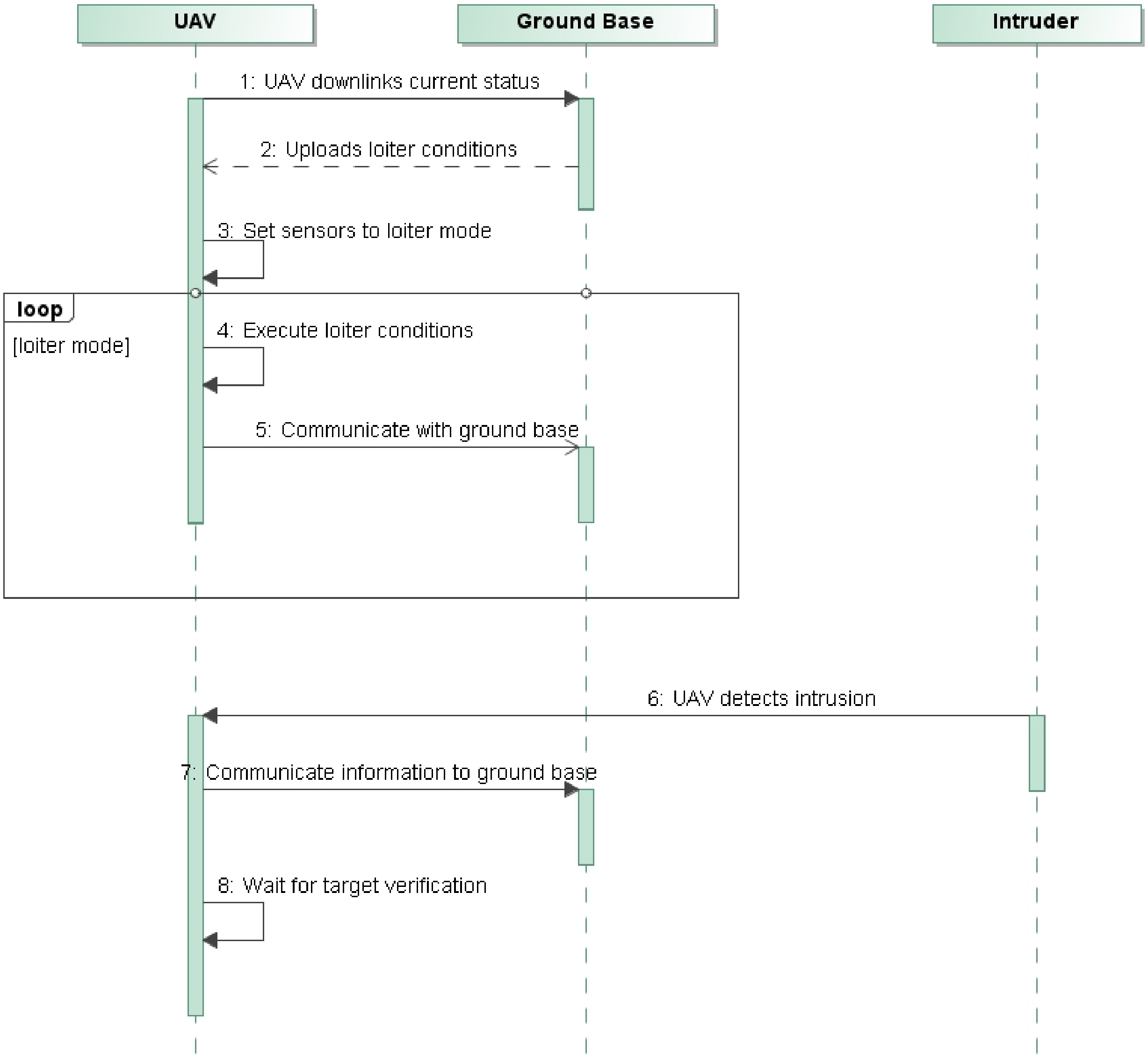


Figure 8: Loiter Sequence Diagram

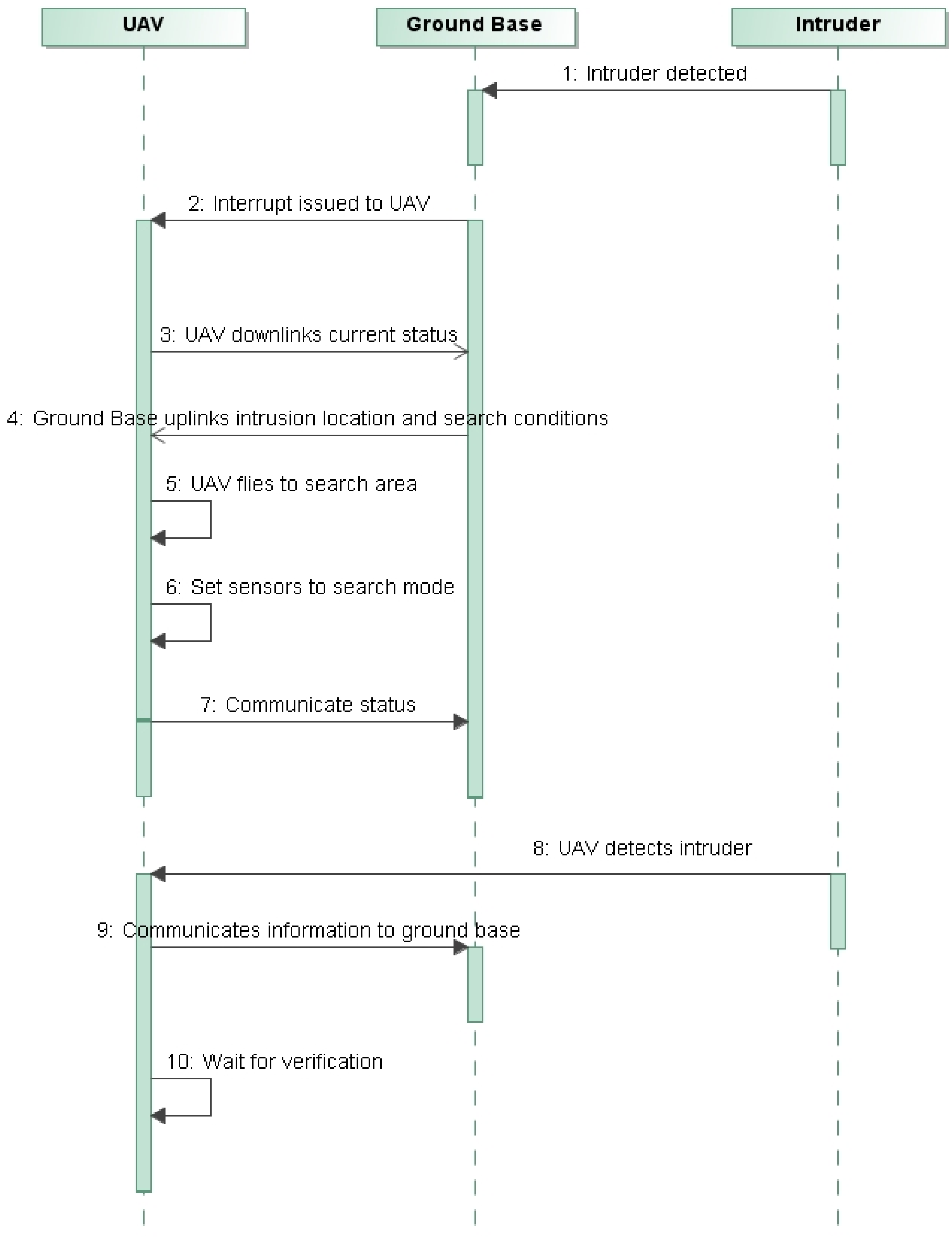


Figure 9: Search Sequence Diagram

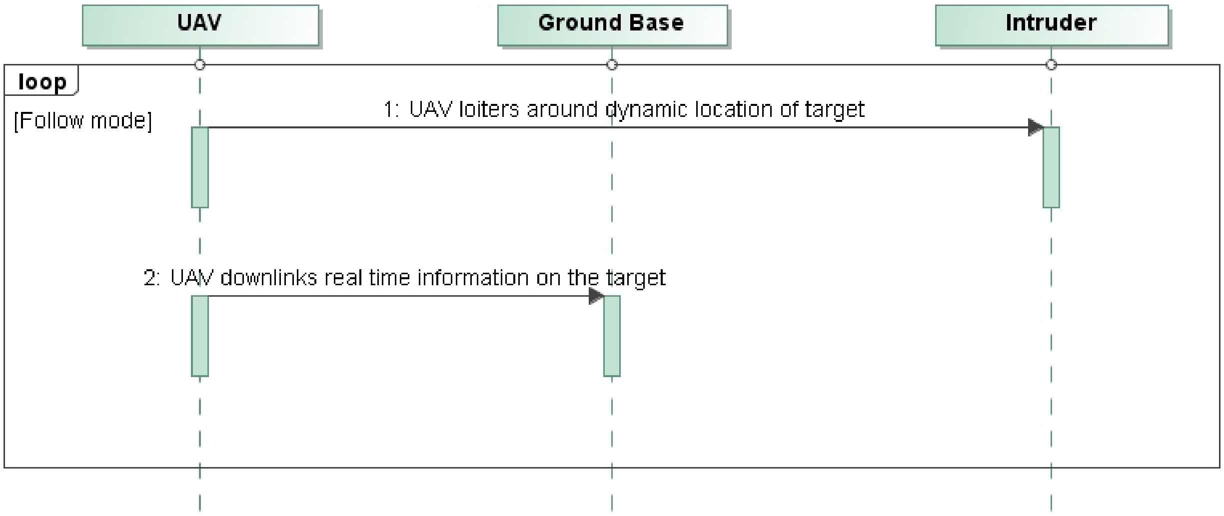


Figure 10: Follow target Sequence Diagram

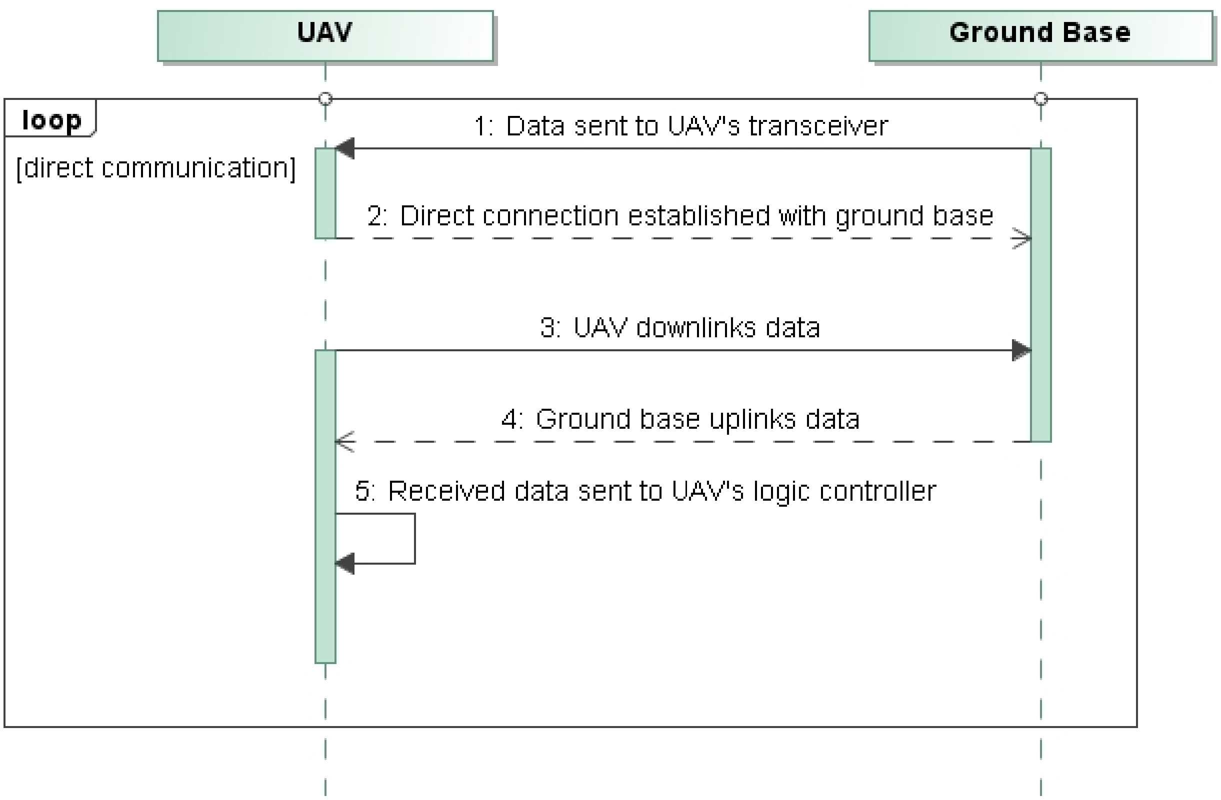


Figure 11: Direct Communication Sequence Diagram

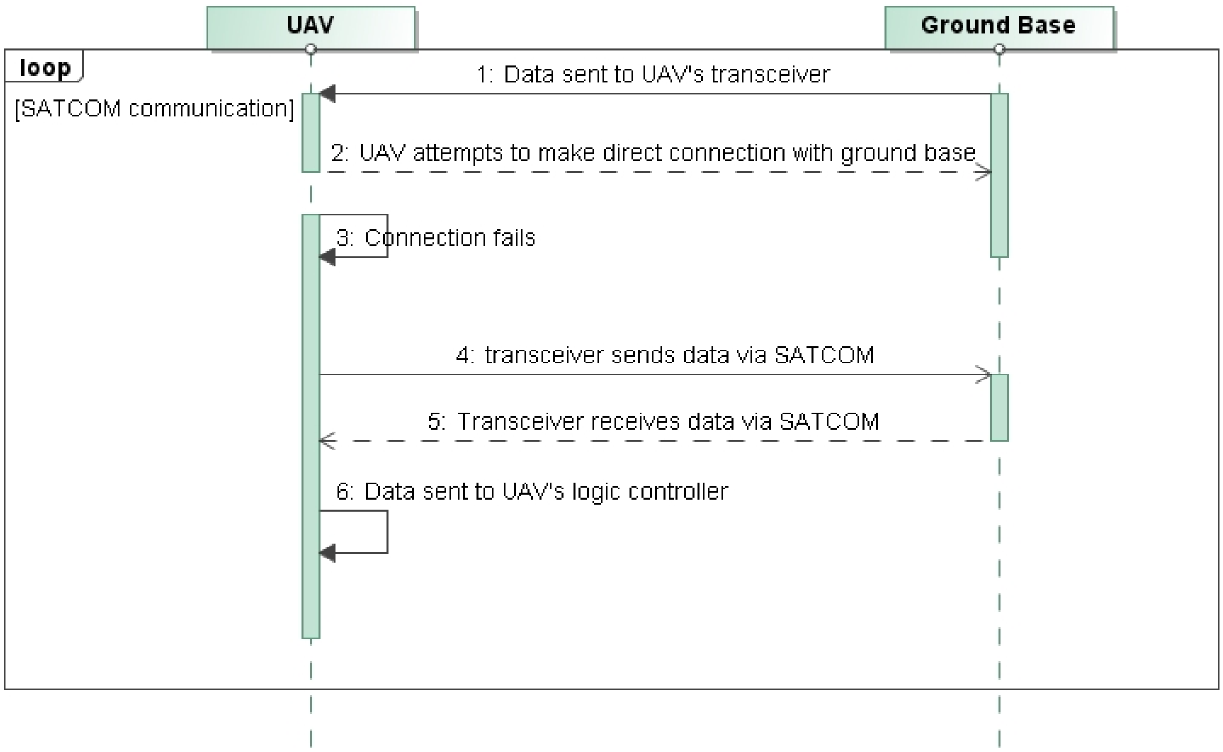


Figure 12: SATCOM Communication Sequence Diagram

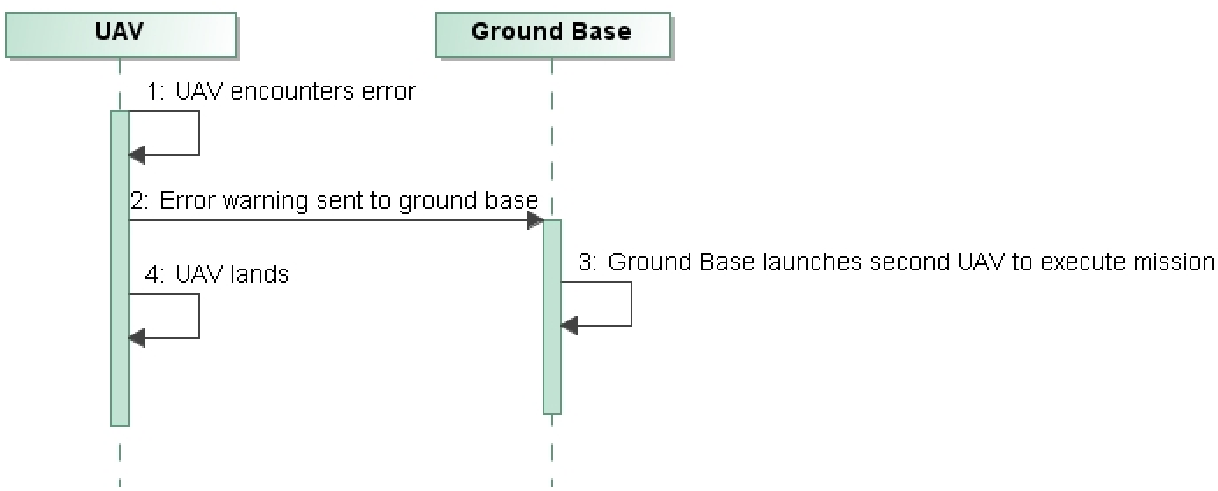


Figure 13: UAV Error Sequence Diagram

4. Requirements Engineering

4.1 High and Low Level Requirements

	HIGH LEVEL	LOW LEVEL REQUIREMENT
1	UAV's must have an effective operational range	**1a.** Range of UAV must be no less than 1600 miles
2	UAV's will be able to remain operational for as long as possible	**2a.** UAV's endurance must exceed 24 hours **2b.** For each UAV in the sky, there must be another flight ready UAV on the ground
3	Sensor package must be able to detect moving ground targets	**3a**. Package must incorporate the use of multi-spectral sensors and provide high quality image/video Cameras **3b.** Sensor package must be able to autonomously detect ground targets **3c.** Package must be able to survey an area of at least 10 square miles at any given time **3d.** embedded software must allow for following dynamic moving targets
4	UAV System must be able to operate regardless of environmental variability	**4a.** Sensor package must provide high quality data independent of environmental conditions **4b.** Communication must remain constant with respect to environmental changes
5	UAV to ground communication must remain constant with respect to distance	**5a.** UAV must communicate directly to base within a range of 90 miles **5b.** Outside of 90 miles, UAV communication must be able to be relayed through geostationary satellites
6	UAV must be autonomous	**6a.** UAV must be able to autonomously follow moving

		ground targets **6b.** UAV must be fully capable of executing autonomous way point flight paths **6c.** UAV must be able to execute real time changes in flight path

4.2 Traceability

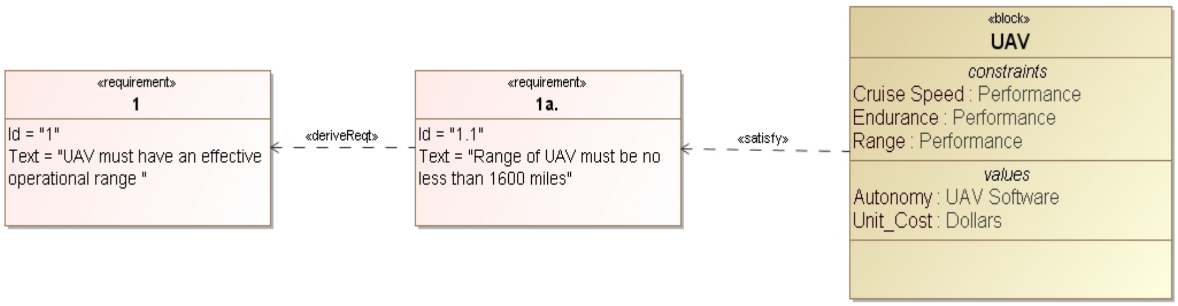
Use Case Requirements Traceability		
Use Case	**Requirement**	**Description**
Patrol	1a, 2b, 3a, 3c, 4a, 6b	Patrol is the most used UAV status and therefore designates many requirements including those based on sensor capabilities and characteristics of the UAVs themselves
Loiter	2a	Loiter is a case which the UAV enters while already in the air. 24 hour plus endurance provides plenty of time for the UAV to survey the area, even if it has already been in flight for many hours
Search	3b, 6c	Especially in the search case, it is imperative that the sensors have autonomous intruder detection and that the flight path of the UAV can be rapidly changed to ensure the necessary area is covered
Follow	3d, 6a	For the follow case, the UAV must be able to autonomously follow an intruder while the sensor package provides real time information about their dynamics
Communicate	4b, 5a, 5b	The UAV needs to be able to have constant communication with the ground base regardless of distance from satellites and weather conditions

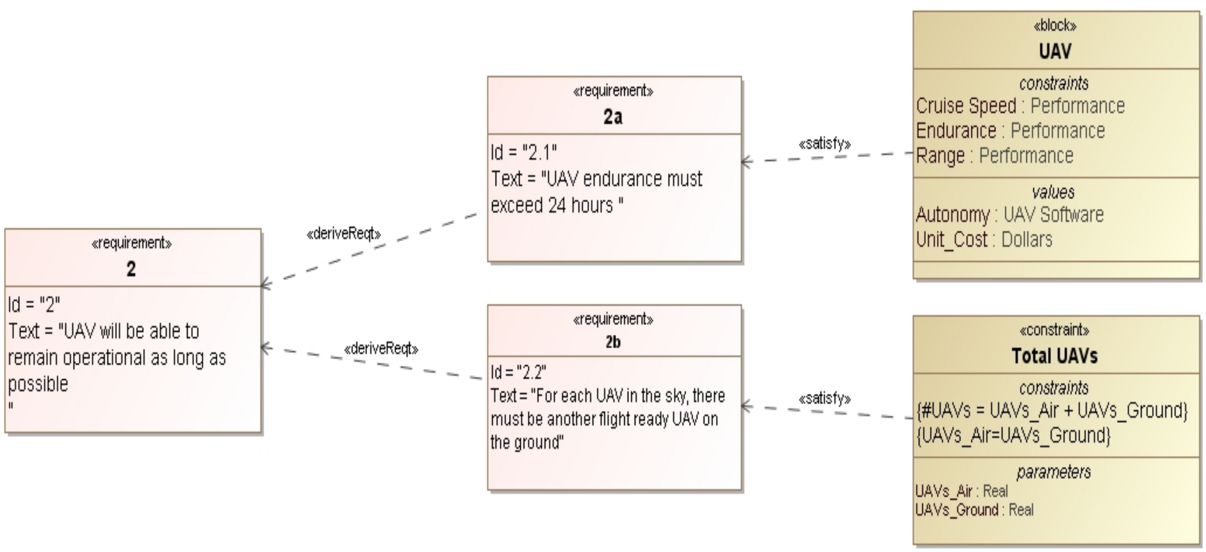
Figure 14: Use Case Requirements traceability

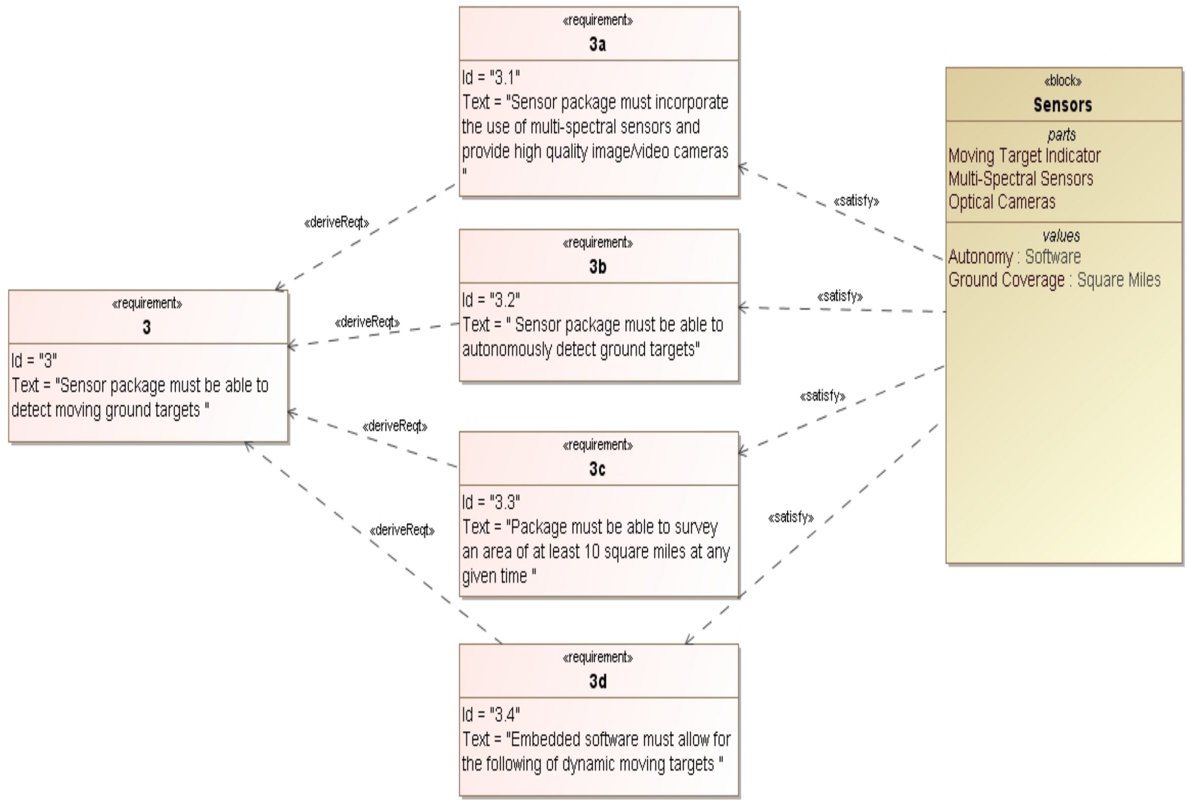
Structural Components	Requirement	Type	Description
Sensor Package	3a	Structure	Package will incorporate multi-spectral sensors and image and video cameras
	3b	Behavior	Sensors will operate autonomously
	3c	Behavior	Coverage area must be at least 10 square miles
	3d	Behavior	The embedded software controlling the sensor package must be able to follow a dynamic target
	4a	Behavior	Sensor data quality must be independent of environmental changes
	6a	Behavior	Sensors will autonomously follow moving ground targets
Communication	4b	Behavior	Ability to communicate is constant regardless of environmental changes
	5a	Structure & Behavior	C-band transceivers communicate directly to Ground base when with-in 90 miles
	5b	Structure & Behavior	VHF transceivers relay information to ground via satellites when outside of 90 miles
UAV	1a	Behavior	Must be able to fly a minimum range of 1600 miles
	2a	Behavior	UAV must be capable of operating for 24+ hours
	2b	Structure	For each UAV in the sky there must be another flight ready UAV on the ground
	6a	Behavior	UAV will follow a moving ground target autonomously
	6b	Behavior	UAV will be able to execute autonomous way point flight paths
	6c	Behavior	UAV must be capable of executing real time changes in flight path

Figure 15: Component Traceability

4.3 Requirement Diagrams



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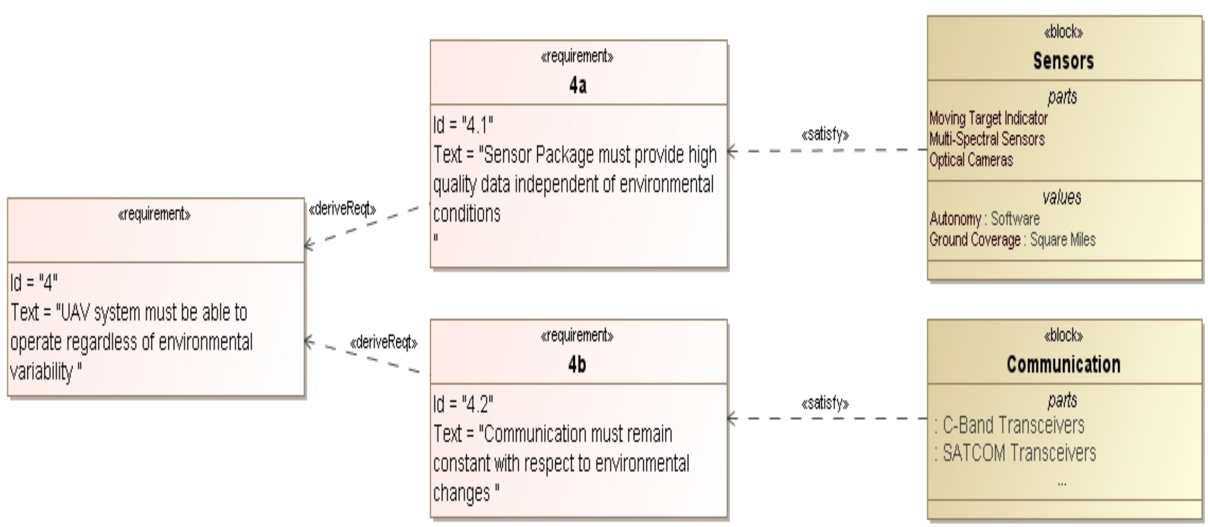
Sensors
parts
Moving Target Indicator
Multi-Spectral Sensors
Optical Cameras
values
Autonomy : Software
Ground Coverage : Square Miles
«satisfy»
«deriveReqt»
«requirement»
3b
Id = "3.2"
Text = " Sensor package must be able to autonomously detect ground targets"
«requirement»
3
Id = "3"
Text = "Sensor package must be able to detect moving ground targets "
«requirement»
3c
Id = "3.3"
Text = "Package must be able to survey an area of at least 10 square miles at any given time "
«requirement»
3d
Id = "3.4"
Text = "Embedded software must allow for the following of dynamic moving targets "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4a
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Text = "Sensor Package must provide high quality data independent of environmental conditions "
«block»
Sensors
parts
Moving Target Indicator
Multi-Spectral Sensors
Optical Cameras
values
Autonomy : Software
Ground Coverage : Square Miles
«satisfy»
«deriveReqt»
«requirement»
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Text = "UAV system must be able to operate regardless of environmental variability "
«requirement»
4b
Id = "4.2"
Text = "Communication must remain constant with respect to environmental changes "
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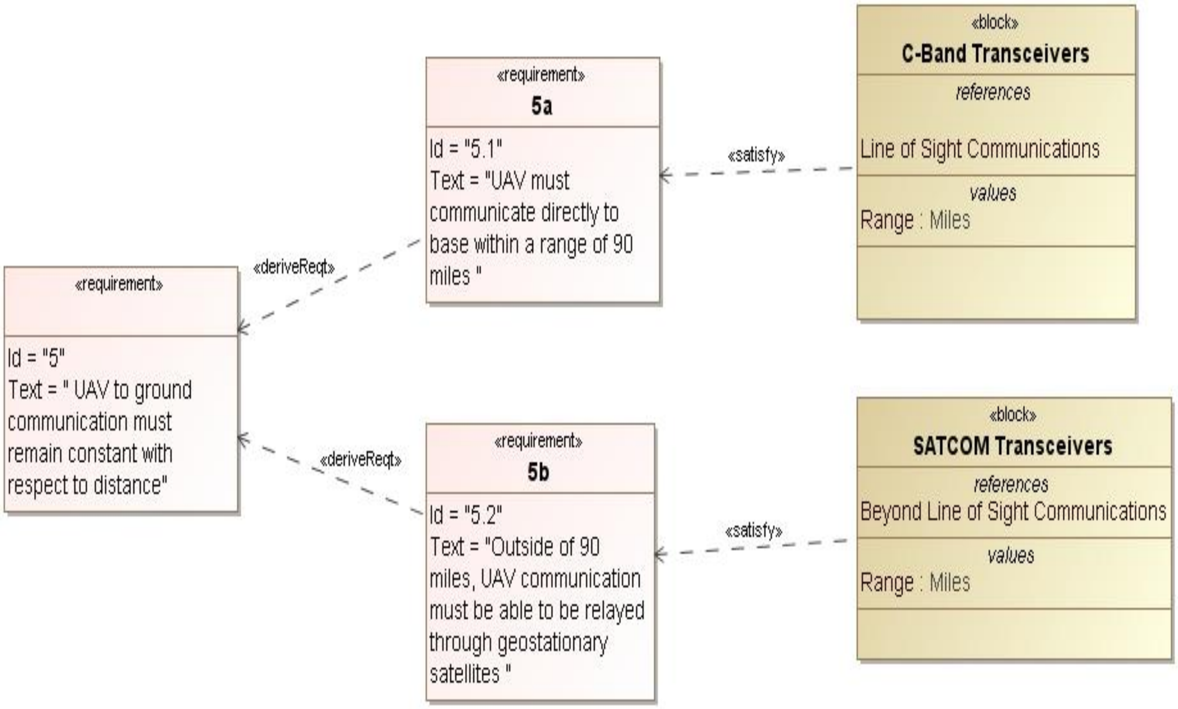
Communication
parts
: C-Band Transceivers
: SATCOM Transceivers
...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C-Band Transceivers
references
Line of Sight Communications
values
Range : Miles
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«deriveReqt»
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«requirement»
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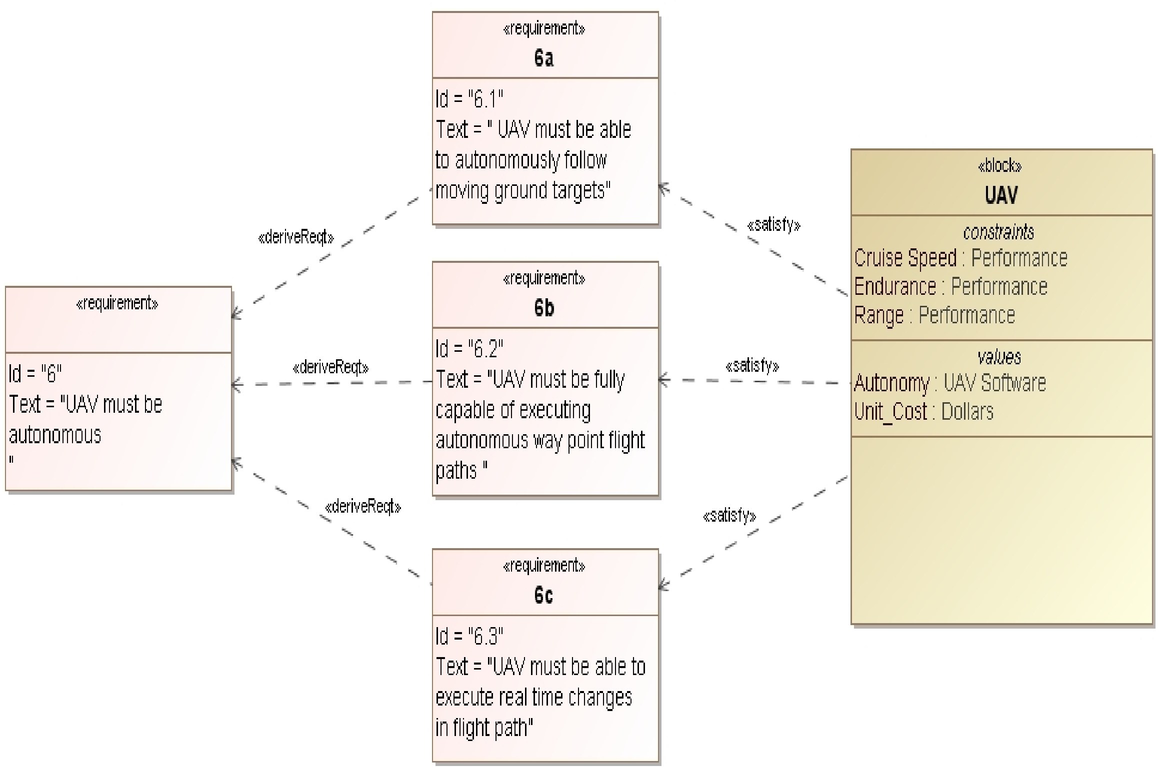
«satisfy»
«block»
SATCOM Transceivers
references
Beyond Line of Sight Communications
values
Range : Miles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«satisfy»
«block»
UAV
constraints
Cruise Speed : Performance
Endurance : Performance
Range : Performance
values
Autonomy : UAV Software
Unit_Cost : Dollars
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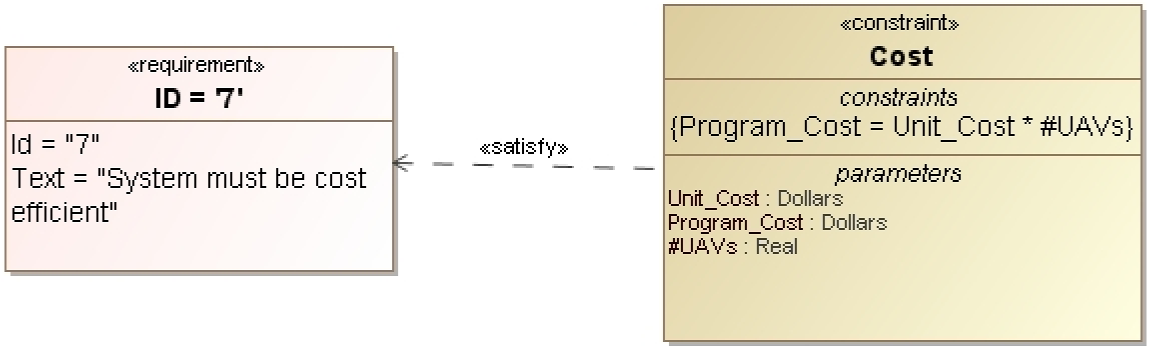
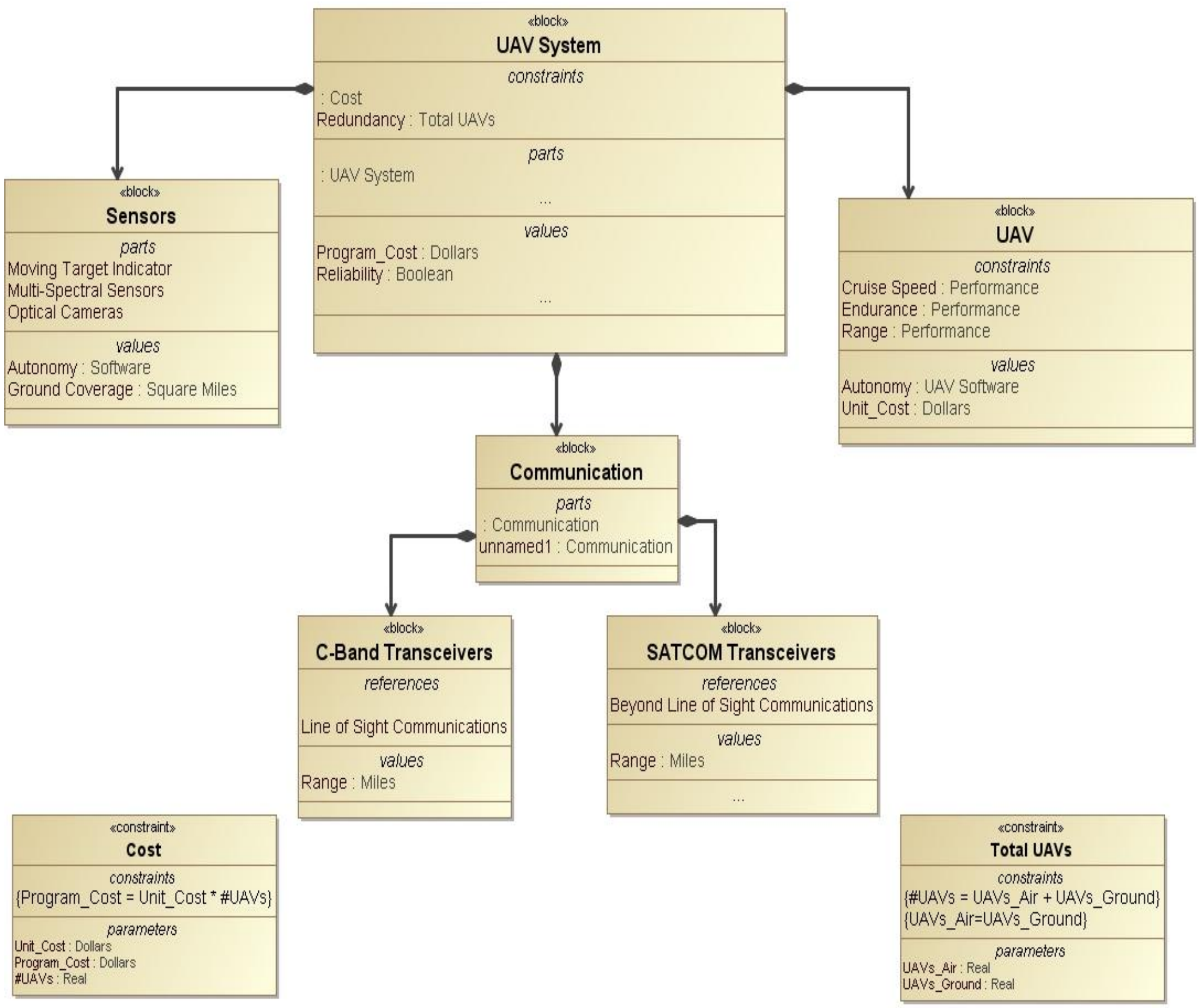
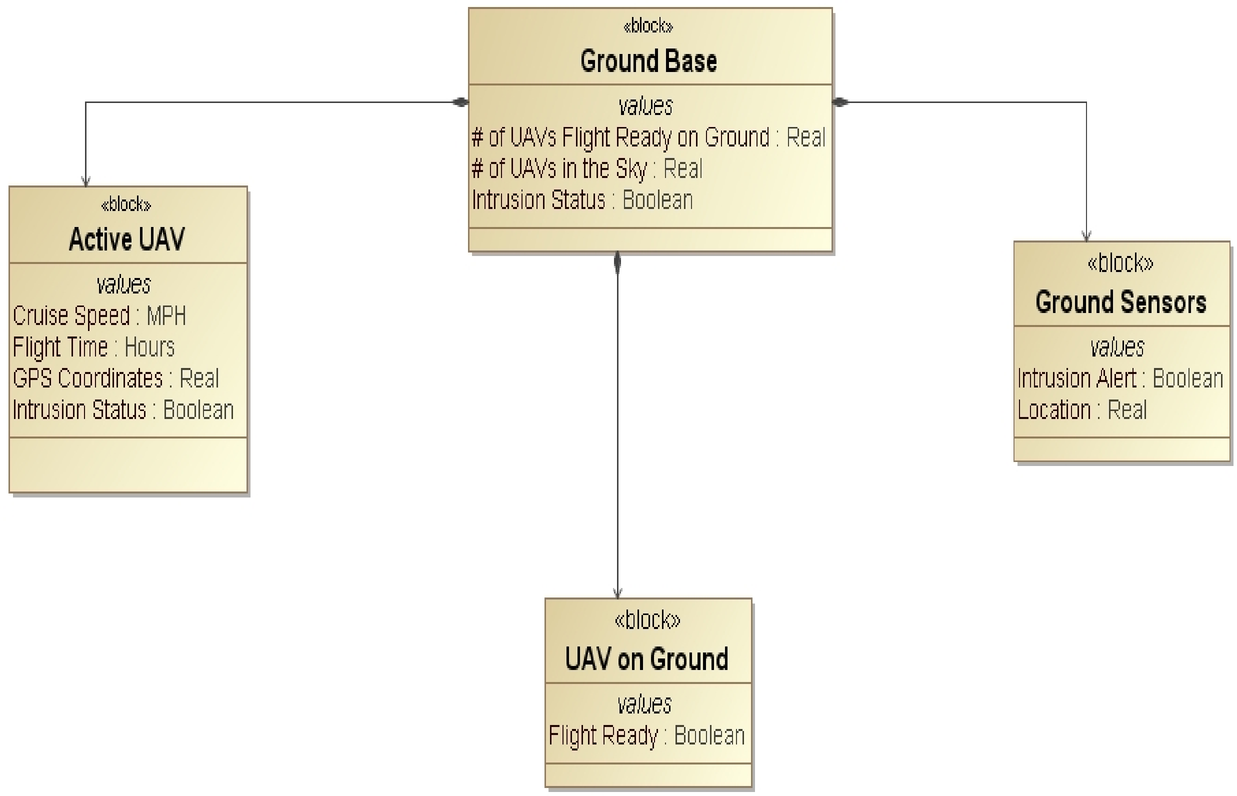


5. System Level Design

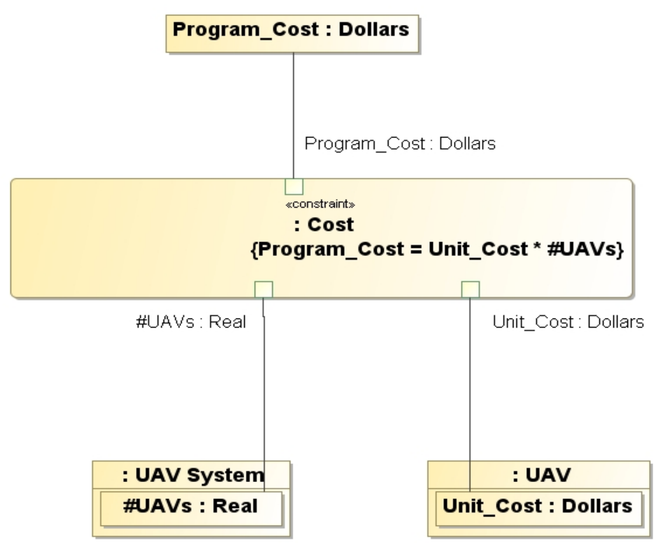
5.1 System Structure



5.2. Ground Perspective Structure



5.3 Parametric Diagram for Cost



6. Trade-off Analysis

The trade-off analysis focuses on three Performance Metrics and four design parameters. In conducting this type of analysis, our goal is to be able to select which UAV would best serve the Boarder Security UAV program.

Performance Metrics:

a) Cost of program
b) Coefficient of Full Coverage
c) Percent of Area Covered

Design parameters:

a) Cruise Speed
b) UAV Range
c) Sensor Package Coverage Area
d) Reaction Time

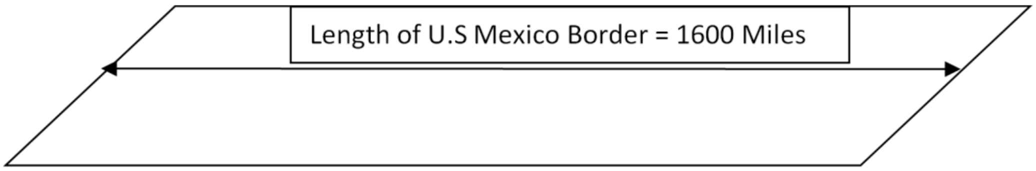
6.1. UAV Specification

The table below gives the design specifications of each UAV. These specifications are used as variables to develop the performance metrics.

UAV	Range (miles)	Endurance	Cruise Speed mph	Unit Cost (millions)	Sensor Package Coverage Area ($miles^2$)
IAI Heron*	217	40+ hours	108	10	15
RQ-9 Reaper	3682	28 hours	172	10.5	15
Predator 1C	2299	36 hours	92	4.5	15
Global Hawk RQ-4A	15524	42 hours	403	68	15
Hermes 450*	124	20 hours	81	2	15
IAI Eitan (Heron TP)	4598	36 hours	105	35	15

*Note: The IAI Heron and Hermes 450 fail to meet Requirement 1a; which states that the range of the UAV must be no less than 1600 miles.

6.2. Analysis Formulation:



Each UAV is assumed an arbitrary sized circular path.

We define the parameter Reaction Time for all UAV's as the time it takes for the UAV to travel the distance from the outside of the circular path to the center. If the Ground control detects an intruder at the center of the UAV's flight path, The UAV is preferred to be able to reach the intrusion area in **one hour**.

Therefore reaction time is set to 1 hr.

Using this time constraint as well as the cruise speed of each UAV, We can formulate size of the circular path with the following equations

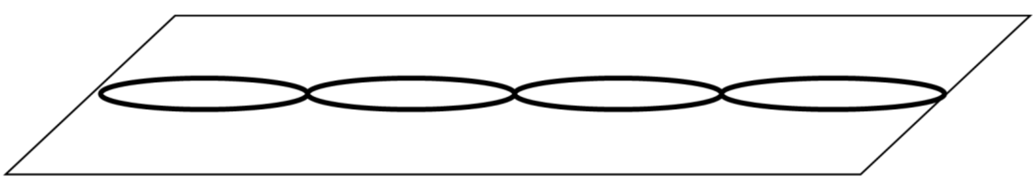
$$R = T \bullet V$$

Where:

- r=Radius of the circular Path (miles)
- T=Reaction Time (hr)
- V= Cruise Speed (mph)

With the radius of the circular path set, the number of UAVs needed for full coverage of the U.S-Mexico border can be obtained by the following equations:

$$\#UAVs = \frac{1600 miles}{2 \cdot r}$$



Next, the radius of each UAV's path is used to obtain the circumference of the path

$$x = 2\pi \bullet r$$

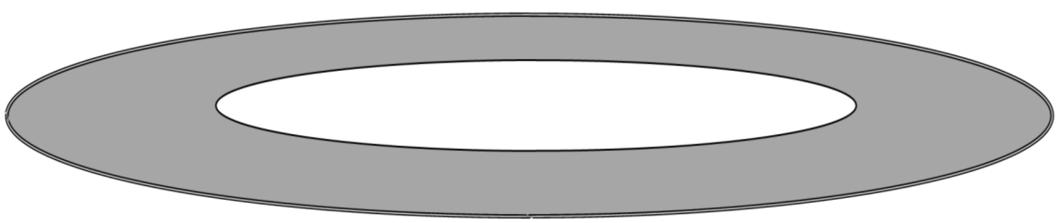
The coefficient of full coverage is based on the number of times the UAV travels around its circular path. Therefore this value is calculated by;

$$C_{of\_Coverage} = R / x$$

Where:

- R= UAV's Range
- X=Circular Path length

Next, we defined the sensor package's ground coverage area to be 15 square miles. This estimate is from the new U.S.A.F Gorgon Stare sensor platform. With this, we can calculate the area the UAV swept out based on the size of the circular patrol path.



The shaded region represents the area of coverage for the UAV. The percentage of total area covered by the UAV is :

$$\%Total\,\mathrm{cov}erage = A_{\mathrm{cov}erage} / A_{Path}$$

6.3. Trade Off Analysis Results

	Number of UAVs	Cost of Program (F_1)	Circumference of Circular Path (Miles)	Coefficient of full coverage (F_2)	Percent of Area Covered (F_3)	Results (W_{total})
RQ-9 Reaper	10	210.00	1084.6	3.40	16.62%	0.07
Predator 1C	18	162.00	574.9	4.00	30.10%	0.26
Global Hawk	4	544.00	2537.9	6.12	7.29%	-0.33
IAI Eitan	16	1120.00	663.7	6.93	26.38%	-0.80

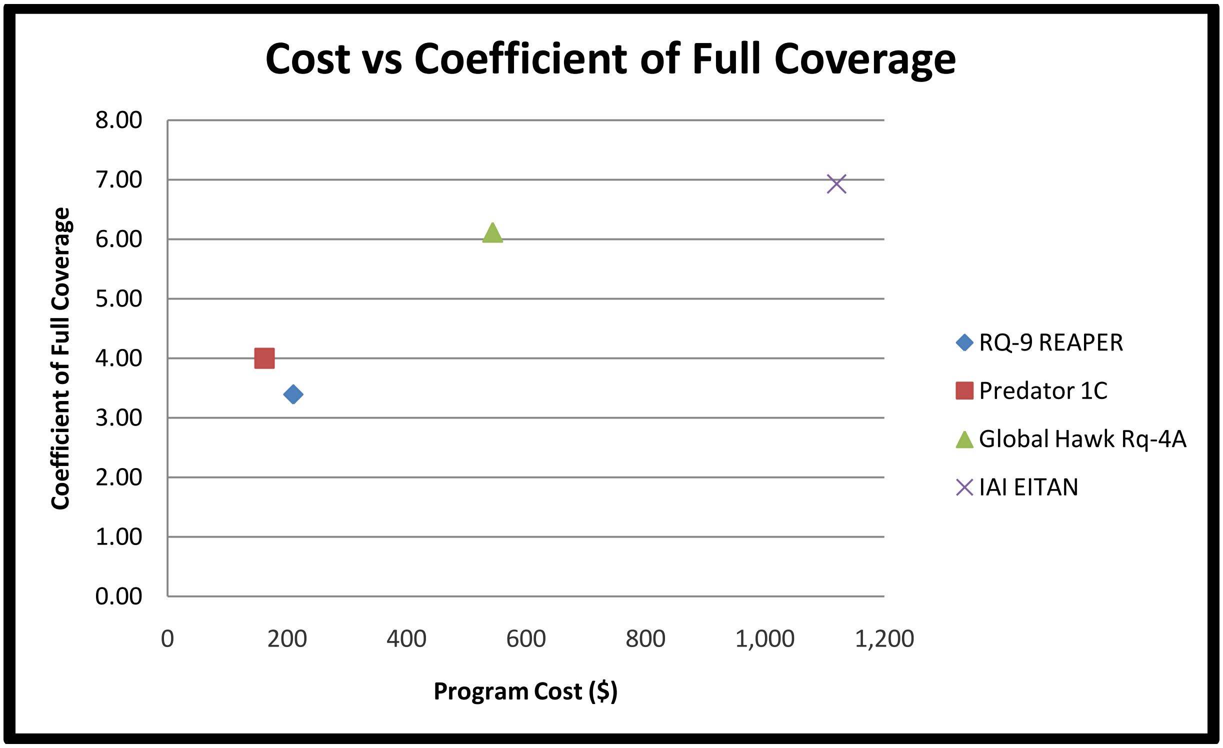
$$W_{total} = F_1 * w_1 + F_2 * w_2 + F_3 * w_3$$

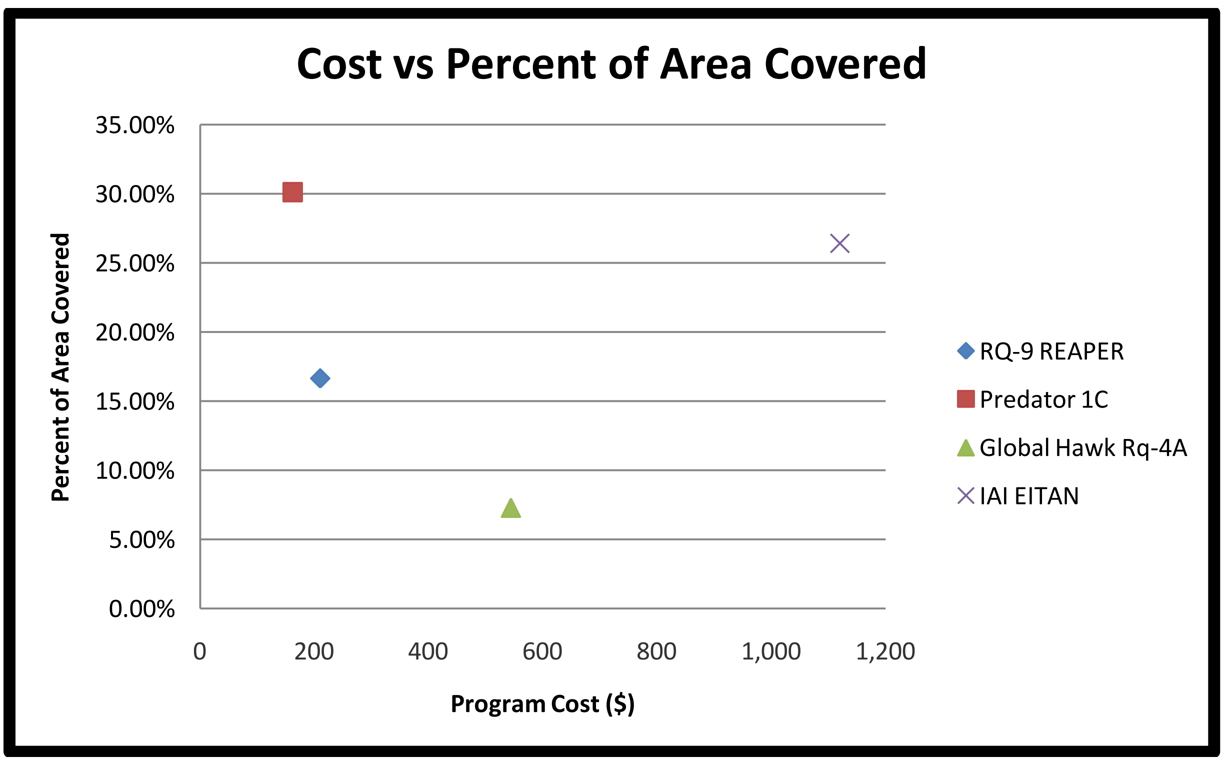
Given that:

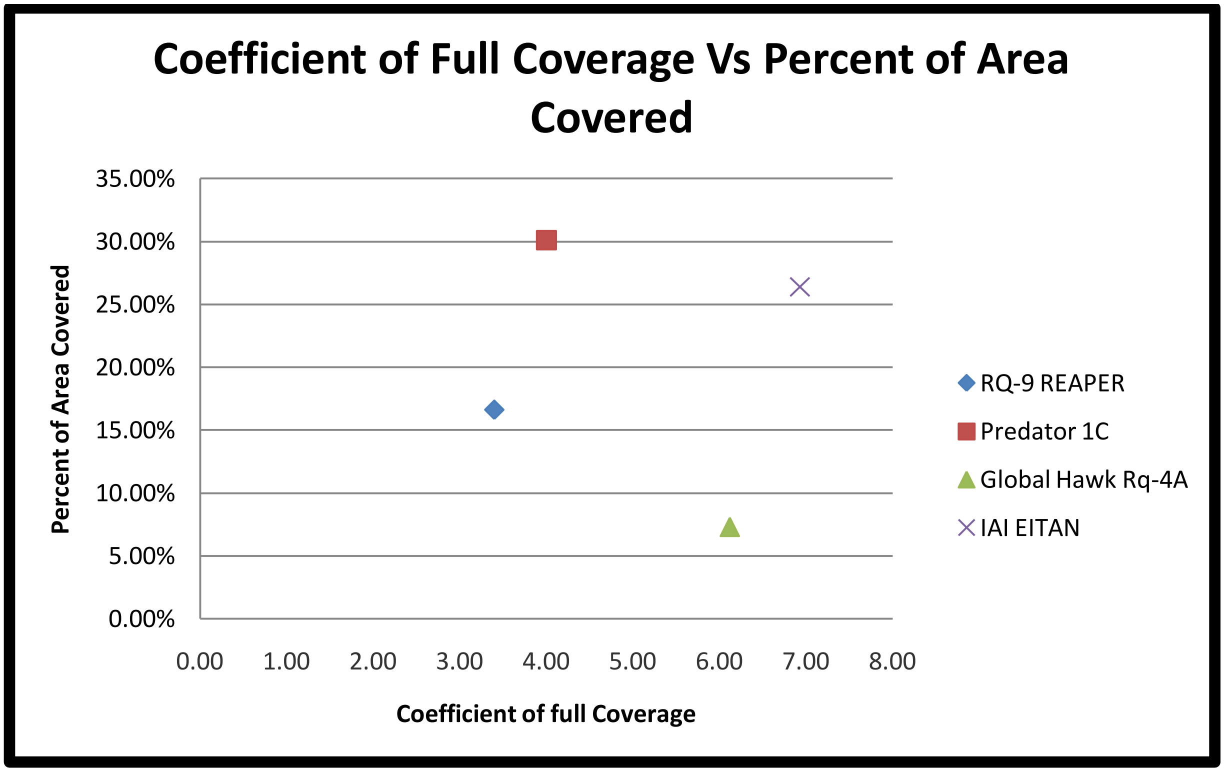
- W_1=-0.6
- W_2=0.2
- W_3=0.2

With these weights, we see that the Predator 1C gives the best combination of cost, coefficient of full coverage, and percent of area covered.

6.4. Graphical Representation of Trade-Analysis







7. Summary and Conclusions

The UAV chosen for the Air Border Security system is the Predator 1-C. Its high levels of coverage, combined with its low cost make it an excellent choice. Requirement verification for the system has already been completed by the industry. This was one of the benefits of using off the shelf technology. The next step in the implementation of this project would be a simulation conducted by someone in the DOD. From there, a test section being built would display the strengths and potential failures of this system. Still, with low cost and ease of implementation, this solution should fare better then Boeing's SBInet.

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9. Credits

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Use Cases and textual scenarios: Whole team

Activity Diagrams: Oluseyi Oni and Aaron Sassoon

Sequence Diagrams: Daniel Flesher

Requirements, Traceability and requirement diagram: Daniel Flesher and Oluseyi Oni

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