University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Raytheon Technologies: SpaceNet

Approvals

	Name	Affiliation	Approved	Date
Customer	Martin Wilson	Raytheon Technologies	Martin Wilson	9/12/2020
Customer	Sheldon Clark	Raytheon Technologies	Sheldon Clark	9/12/2020
Customer	Mark Werremeyer	Raytheon Technologies	Mark Werremeyer	9/12/2020
Course Coordinator	Jelliffe Jackson	CU/AES		

1.1. Project Customers

Martin Wilson 16800 Hughes Dr, Aurora, CO 80011 martin.wilson@raytheon.com	Sheldon Clark 16800 Hughes Dr, Aurora, CO 80011 sheldon.c.clark@raytheon.com	Mark Werremeyer 16800 Hughes Dr, Aurora, CO 80011 mark.r.werremeyer@raytheon.com

1.2. Team Members

Ryan Burdick (Manufacturing Lead) rybu3974@colorado.edu (720)299-7830	Sam Firth (Safety Lead) safi0652@colorado.edu (970)227-4062
Noah Francis (Software Lead) nofr6730@colorado.edu (720)233-3831	Jordan Gage (Systems Engineer/Financial Lead) joga0413@colorado.edu (970)381-6320
E Forest Owen (Electrical Lead) efow4675@colorado.edu (907)687-9744	Tyler Pirner (Systems Engineer) typi6819@colorado.edu (303)437-9106
Keith Poletti (Software Lead) kepo6935@colorado.edu (720)375-0117	Ryan Prince (Project Manager) rypr9042@colorado.edu (310)968-0386
Israel Quezada-Cordova (Electrical Lead) isqu6841@colorado.edu (720)545-5237	Colin Ruark (Software Lead, Asst. Project Manager) coru0688@colorado.edu (530)613-9230
Benji Smith (Systems Engineer) besm9389@colorado.edu (303)552-7321	N/A

2. Problem or Need

With the influx of spacecraft over the past few years, low Earth orbit (LEO) is a highly contested domain. The need for monitoring has significantly increased with the launches of large satellite constellations such as Starlink, Kuiper, and OneWeb. The Defense Intelligence Agency claims increased space congestion will require "better capabilities to track and identify objects and prevent a collision in space."[1] To this endeavor and ensure future space exploration, the aerospace community pushed for the development of a full picture of Space Domain Awareness. Part of this goal is to develop inexpensive, accessible sensors that can collect large amounts of data when deployed in a web-like network. This data can be used to track the aforementioned large constellations and potentially allow for collision avoidance analysis in the LEO environment.

High fidelity ground systems to track space debris are costly and not easily built. As a result, current ground tracking system infrastructure is sparsely scattered across the world. To provide a bigger net to track satellites, Raytheon proposed SpaceNet. SpaceNet focuses on creating low cost and manufacturable sensor units. These sensor units will have a low fidelity but will make up in ground covered and increase network capability. Ideally, thousands of sensor units could be deployed across the continental US and provide data back to the main database. With four sensor units picking up a satellite's signal, orbital determination algorithms will be able to determine the current orbit of the satellite. This project will focus on developing a proof of concept with four sensor units being able to determine a satellite's orbit. In addition, SpaceNet will have the capacity to monitor the characteristics of a satellite's signal (e.g. amount of data being transmitted, change in downlink location, etc)

This project aims to explore the possibility of adding low fidelity receivers in a large array to provide further data into the state of space which should allow for better satellite tracking, collision avoidance, and an optimized use of higher fidelity tracking systems such as ground stations.

3. Previous Work

Based on the provided Defense Intelligence Agency "Challenge to Security in Space" [1] document, there has been considerable previous work done in the field of Space Situational Awareness (SSA). Alongside the U.S., both China and Russia have especially developed several different methods to determine a space object's location and the ability to track and predict its future location. With the ability to track an unknown satellite, it provides the ability to determine the specific intent for a particular satellite.

The general methods that China, Russia and the U.S. use to gain information regarding SSA, have been networks of sensors that include telescopes, radars, etc. For example, there is a company based in Silicon Valley called LeoLabs that utilizes currently three large radar networks to provide a subscription service to track and provide real-time data on the location of satellites and debris. LeoLabs's older radar technology utilizes UHF band electronics, whereas their newer radar technology involves the use of S-band electronics. This company also chooses to utilize radar instead of other methods due to the fact that it is less susceptible to the effects of sunlight, clouds, rain, snow, and wind.

As mentioned previously, there is possibly an endless amount of work dedicated to SSA, and the SpaceNet project will hopefully be a tiny portion of the work done in this field. This project may not have the necessary capital to produce the results that companies like LeoLabs can provide, but we hope to provide users with similar data on SSA while also being versatile by how and where data can be collected.

4. Specific Objectives

Sensor Unit Packaging

Level 1	*Sensor Packaging shall integrate all hardware *Sensor Packaging shall weigh less than 100 lbs and be contained within 5'x5'x5' volume
Level 2	*Packaging will provide enough EMI immunity to allow for the calculation of the target's orbit. *Sensor packaging shall keep components within operating temperature range in all expected temperatures and conditions(heat (sun), water (rain), cold, wind, variable (snow)) - Thermal test to verify selected components with minimal operating temperature range is not exceeded (all components will remain operational). *Sensor shall be a self-contained unit with access to an external power source and a network interface *Packaging shall use standard USB connectors, Coaxial RF connectors, and NEMA 5-15 socket
Level 3	*Sensor packaging shall withstand 3 weeks of varied weather conditions with no sign of compromise (no box leaks,) *Packaging shall be mountable to a fixed installation. *Packaging shall use standard residential NEMA 5-15 socket at standard 120 V / 60 Hz / 15A residential service *One unit produced (w/ schematics, procedure, and manufacturing analysis)
Level 4	*Four units produced and operational
Sensor Unit Data Acquisition Subsystem	
Level 1	*Sensor shall use an commercial SDR unit *Sensor shall use standard connectors for ease of manufacturability *Sensor shall collect one of two bands A or B(Single Band) *Unit shall be networked enabled with the ability to be controlled remotely from a PC
Level 2	*Onboard software shall be able to transmit data over a network. *Software shall be able to return to nominal operation after an power or network outage - GNU radio shall be used for signal processing
Level 3	*Unit shall record and transmit data on 24/7 basis, assuming constant power and network access - Unit demonstrates ability to collect and transmit data over a 24 hour period with additional verification during the planned 3 week field test. *Error analysis report comparing SpaceNet to higher fidelity alternatives - Compare the data gathered with SpaceNet with the data gathered by higher fidelity systems, like an S-band Antenna or a ground station.
Level 4	*Sensor shall collect A and B Band Signals(Dual Band) *Sensors shall be equipped with a GPS receiver for RF signal timing
Combined System	
Level 1	*One test bench unit produced and capable of collecting signal data
Level 2	*One unit produced and field tested - By satisfying the 3 week field operation withstanding all nominal ambient weather

	* Capability to send data over a network for data processing.
Level 3	*Four units produced, mounted, and operational. *Manufacturing documentation (schematics, procedure, manufacturing analysis, suggested improvements, and ways to drive down cost) *Processed Data from 4 sensors shall be capable of producing orbit prediction

5. High Level Functional Requirements

5.1. List of Requirements

The following outlines the functional requirements for the project. These requirements must be satisfied in order for base mission success. These requirements will flow down into more specific requirements to drive design.

1. The sensor unit shall be able to detect radio signals from satellites in low Earth orbit.
2. The sensor unit shall upload data through the internet for further analysis.
3. The sensor unit shall survive and continuously transmit data in all possible weather conditions.
4. The received sensor data shall use orbital determination algorithms to estimate a satellite's orbit and position in orbit.

5.2. Functional Block Diagram

The sensor unit will draw power from a 120 V / 60 Hz / 15A source. The component will need lower DC voltages that will be determined by the specific parts. Hence the unit will require some power regulation. To protect the signal from noise, the power regulation must be done on an independent PCB. This shall provide power to the rest of the sensor unit.

The signal processing board shall provide gain to the antenna signal. The amplified signal will pass through the software-defined radio(SDR), which will do the majority of the signal processing. Depending on the SDR, an analog to digital converter(ADC) might be required. With the signal digitized, it can be sent to the onboard controller. The signal can be either stored or transmitted via a network connection for further processing. The onboard controller will be the brain of the sensor units. Its functions will include tuning the radio, storing/transmitting data, and reporting the sensor's status.

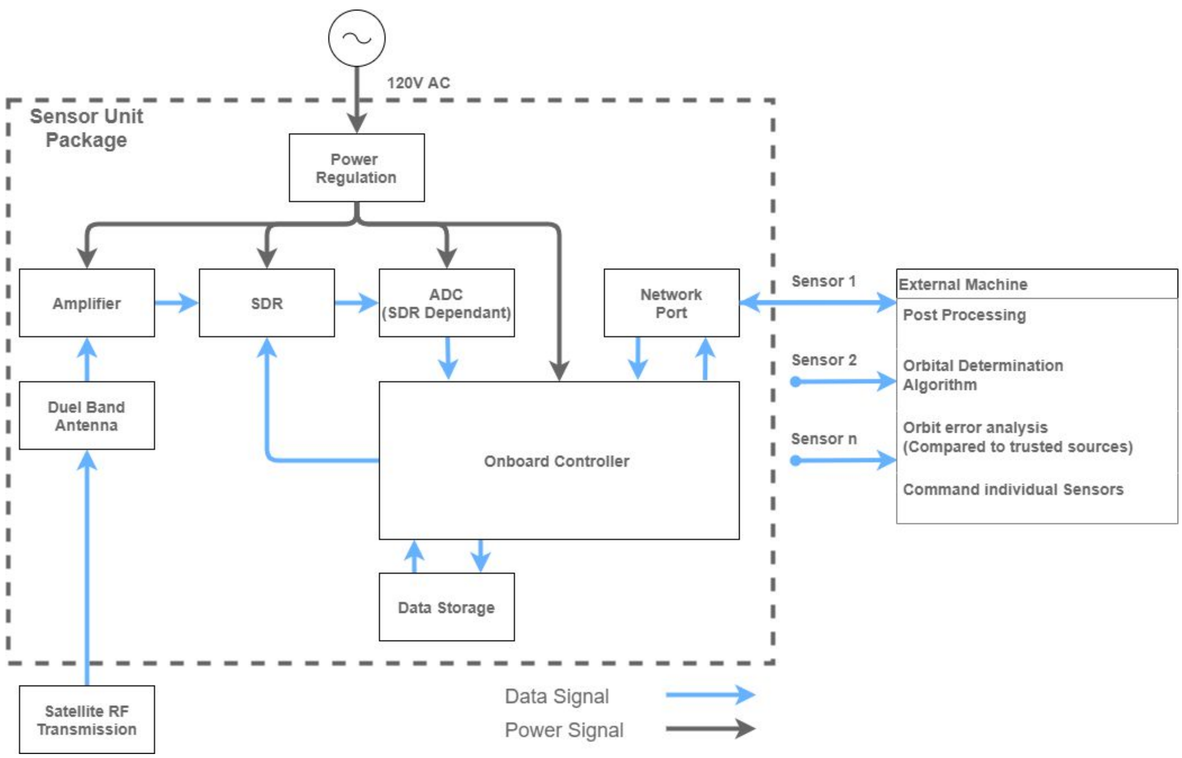

Figure 1: Functional Block Diagram of a single sensor unit

5.3. Concept of Operations

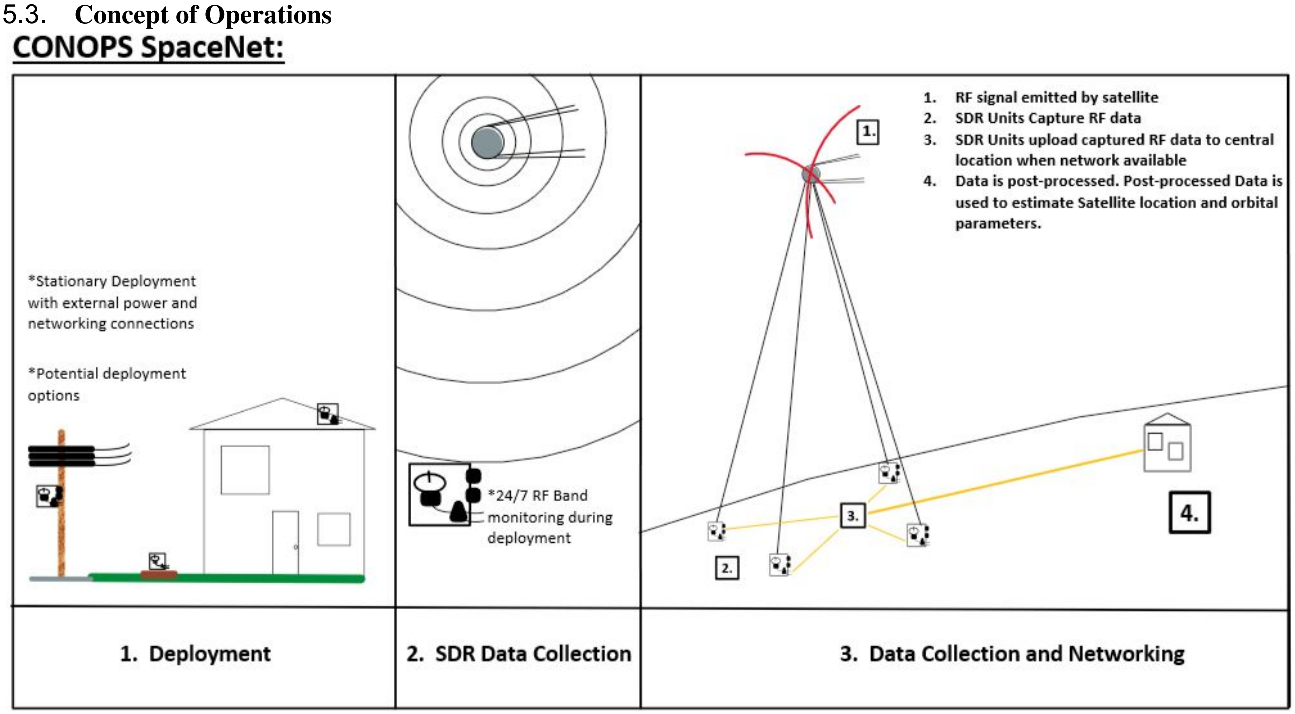

Figure 2: Concept of Operations for sensor network

As seen by the diagram above, the specific mission of the SpaceNet Project is to have the SDR sensor system deployed in a stationary position with an external power source and network connections. The system will then complete 24/7 monitoring of the R/F band during its deployment. The monitoring done by the system is encompassed by the following items: the SDR units capture the RF Data emitted by the observed satellite, then the SDR units upload the captured RF data to a central processing location, when network connection is available. From this point, the RF data will be processed, in which the goals are to determine the emitting satellite's location, and orbit parameters.

6. Critical Project Elements

6.1. **Sensor Unit SDR:** The SDR determines our ability to collect usable data

6.2. **Command and Control Software:** Without this the sensor loses robustness and loses its versatility and justification. In the instance of a power outage, software needs to enable full system recovery so on site maintenance is kept to a minimum.

6.3. **Sensor Packaging robustness:** Packaging needs to be robust for the same reasons as above; if these break after a month and need to be replaced the overall benefits of the low fidelity tracking model go down.

6.4. **Data Acquisition System:** Data needs to be stored in the system and transferred when the link budget allows so gaps in system coverage are minimized.

6.5. **Networkability(multi units):** Enables the verification of satellite system status checks and allows for rough orbital determination.

6.6. **Manufacturability:** One of the primary main elements as specified by our client Raytheon, was that the sensor packages must be inexpensive and easily assembled in order to be deployed across a wide area. this way they can behave like a course net, tracking a large portion of the overhead satellite activity.

7. Team Skills and Interests

Critical Project Elements	Team member(s) and associated skills/interests
Sensor Unit SDR	Noah Francis, Ryan Prince
Command and Control Software	Keith Poletti, Tyler Pirner
Sensor Packaging robustness	Ryan Burdick, Benji Smith
Data Acquisition System	Jordan Gage, Colin Ruark, Tyler Pirner
Networkability(multi units)	Israel Quezada-Cordova, Forest Owen
Manufacturability	Samuel Firth, Ryan Burdick

8. Resources

Critical Project Elements	Resource/Source
Data Acquisition System	LASP. LASP facilities will be used for data verification and orbital prediction error analysis
Command and Control Software, Sensor Unit SDR, Data Acquisition System	Advanced Electronics Lab(CU). The AEL provides easy access to electronics development equipment such as PCB printing and NI DAQ systems

9. References

[1] DIA "Challenge to Security in Space", Defense Intelligence Agency, January 2019, from www.dia.mil/Military-Power-Publications.

[2] The Mapping Platform for Space. (2020, June 01). Retrieved September 08, 2020, from https://

www.leolabs.space/

[3] MIL_STD_810H, Department of Defense(2019, January 31), Retrieved September, 09, 2020, from https://www.iest.org/Standards-RPs/MIL-STD-810H

[4] "NASA Systems Engineering Handbook", NASA(2016), Retrieved September, 09, 2020, from https://www.nasa.gov/connect/ebooks/nasa-systems-engineering-handbook

[5] "Practical Electronics for Inventors" Fourth Edition, Paul Scherz, Simon Mark, 2016 published by McGraw-Hill Education