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Executive Summary

Christopher Simpson will build a 130-430 MHz dual-use software-defined radio to test inter-formation networking and precise navigation and timing. This device will later use 24-GHz Ka-band to allow data-rates of 1-Gbps. The prototype will be presented in March 2020 at the conclusion of the effort. The payload functions as a passive radar and directed beam by utilizing electronic beam-forming, passive illumination, and network time reference protocols. During AY 2019-2020, 2 demonstration CubeSats will be built to test this game-changing technology in formation flying.

Mr. Simpson intends to collaborate with Marshall Space Flight Center (MSFC) researchers developing inter-CubeSat communication using a peer-to-peer topology. The mesh network architecture MSFC researchers are developing is intended to allow for data exchange between spacecraft with no central router. The waveform currently in use will be leveraged to reduce development risk.

Addressing the Scientific and Technical Challenges

It has been 50 years since the United States first stepped on the Moon. The Lunar Exploration Advisory Group (LEAG) has suggested enhancing the NASA and the United States' return to the lunar surface by determining the temporal and spatial distribution of water over long temporal baselines [1]. The University of Alabama Remote Sensing Center suggested addressing the large gaps in Antarctic ice thickness data (despite over 50 years of airborne radar soundings) with a 50 smallsat formation. In order to achieve the necessary fine resolution in the along track direction, a large aperture must be synthesized by the formation [2]. The same smallsat formation would be able to provide the necessary resolution to map the water distribution.

There are several challenges to this formation. The necessary resolution requires close distances, less than a 100-m in some cases, in the along-track and cross-track directions. Highly accurate and Precise Navigation and Timing (PNT), or state knowledge, is required for post-processing and safe formation flying. Using a synchronized phased array Software Defined Radio (SDR) an intra-formation network will communicate PNT, telemetry, and their neighbors' tracks. The SDR will double as passive radar using the intra-formation network as an illuminator of opportunity to track neighbors.

NASA Roadmap 2015 – TA 5.5.1.1 looks for SDRs, "…which sense and adapt to link and system conditions, to efficiently increase data transfer and reduce user burden." [3] With good reason! Smallsats still struggle to precisely point. This reduces the capability of high frequency links like Ka-band systems which are highly directional. The phased array take advantage of electronic beam-forming alleviate the precise pointing requirements.

SCaN is a testbed currently on the ISS to enable SDR advancement and applications in space. All applications using SCaN make use of the Space Telecommunications Radio System (STRS) Architecture Standard, NASA-STD-4009A w/Change 1 [4]. The applications developed for this application will be added to the repository maintained by Goddard Space Flight Center (GSFC) for future researchers.

Networked swarms have yet to be demonstrated. NASA Ames Research Center's Edison Demonstration of Smallsat Networks (EDSN) mission of eight small satellites was lost due to launch failure. The EDSN mission demonstrated networked swarms are less of a hardware and more of a systems and software engineering problem. Two 1.5U Network & Operations Demonstration Satellites (Nodes) deployed from the ISS in 2016 as NASA Ames attempts to complete some of the EDSN tasks. MSFC is also developing inter-CubeSat communication using a peer-to-peer topology mesh network architecture. This will allow for exchanging telemetry and other data between spacecraft with no central router [5]. I hope to partner with this group as I plan to make use of network time reference would like to avoid development of a new waveform or TDMA system.

The Remote Sensing Center (RSC) at The University of Alabama (UA) has facilities, staff, and expertise to support the development and manufacture the prototype. The RSC currently hosts three electronics and radar laboratories and is currently in the process of installing an anechoic chamber and satellite ground station. The RSC has already produced several radars for remote-sensing solutions. The Remote Sensing Center at the University of Alabama is proposing and developing satellite missions and EMF/RF technologies for soil, snow, and littoral water observations. Proposed missions are in the 5 year timeframe for smallsat vehicles and 10+ for major collaborative missions.

The faculty advisors have the necessary experience and resources to support me.
Dr. Jeong's current research interests include 5G millimeter-wave antenna and system, adaptive RF front-ends, electromagnetics, RFIC (Radio Frequency Integrated Circuit), system-on-package, high-speed interconnects, wireless power transfer and biomedical electronics. In addition, Dr. Jeong holds more than 60 international patent and patent applications in the areas of wireless communication circuit, microwave and millimeter wave system, V2X (Vehicle to Everything), antenna, wireless power transfer and bioelectronics.
Dr. O'Neill is an expert in navigation and rapid prototyping. He is currently developing navigational tools to remotely operate UAVs. His current research interests include aircraft aerodynamics rapid prototyping with deep integration into a multidisciplinary design environment, computational fluid dynamics, or CFD, for aerodynamics; flight dynamics; stability and control; loads; and aeroelasticity, exterior ballistics, and integrating vehicles and remote sensing radar.

Motivating Students

As a research-oriented graduate student at the University of Alabama, I have demonstrated an ability to manage complex tasks and meet deadlines.

References

[1] Lunar Exploration Analysis Group, "Lunar Human Exploration Strategic Knowledge Gap; Special Action Team Review," September 2016. < https://www.nasa.gov/exploration/library/skg.html>

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[3] "TA 5.5 Integrated Technologies," *2015 NASA Technology Roadmaps; TA 5: Communications, Navigation, and Orbital Debris Tracking and Characterization Systems,* NASA Headquarters, July 2015. < https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_5_communication_and_navigation_final.pdf>

[4] Space Telecommunications Radio System (STRS) Architecture Standard; NASA-STD-4009A w/CHANGE 1, 14 March 2018.

[5] Yost, B. "09. Communications," *State of the Art of Small Spacecraft Technology*, last modified 12 March 2019. <https://sst-soa.arc.nasa.gov/09-communications>