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Bento BoxModular/Recoverable Stratospheric Balloon Capabilities to Support Distributed Maritime Operations

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BENTO BOX—MODULAR/RECOVERABLE STRATOSPHERIC BALLOON CAPABILITIES TO SUPPORT DISTRIBUTED MARITIME OPERATIONS

EXECUTIVE SUMMARY

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Project Summary

In investigating the use of a modular near-space system for Distributed Maritime Operations (DMO), a notional concept of operations (CONOP) was developed to demonstrate the feasibility of a future system that can be used by Naval Special Warfare (NSW) to maximize the breadth of its resources and provide cross-platform data. This CONOP focused on a satellite communications (SATCOM)-denied environment in the Arctic, which showed that it is feasible for a high-altitude balloon (HAB) system to provide persistent overwatch and electronic reconnaissance (POWER) capabilities when existing commercial stratospheric systems are leveraged and incorporated into the mission architecture. Additionally, the reliability and robustness of this system, named the Bento Box, survived environmental testing. An ADALM-Pluto software-defined radio (SDR) was integrated with the Bento Box for this portion of the study as a bounding case for commercial-off-the-shelf (COTS) equipment that can withstand the Arctic environment. End-to-end system testing between the integrated HAB system and two PRC-152 ground user radios in a simulated ground test environment serves as a proof of concept for mesh networks with low-cost COTS equipment that are expendable but easily sustainable within a DMO construct (Williams, 2022).

Investigation of machine learning (ML) algorithms to improve overall geolocation accuracy revealed that math-based geolocation processing continues to be more accurate than ML-derived accuracy. Specifically, for maintaining positional accuracy for targets that are no longer emitting an RF signal, Kalman filtering with a chi-squared statistical anomaly detector can accurately estimate the target location. Future efforts may include exploring the use of ML during signal processing.

Keywords: *high-altitude balloons, near-space platforms, distributed maritime operations, DMO, mosaic warfare, tactical maneuvers, contested environment*

Background

Operating in hostile, contested environments is a significant concern across the Department of Defense, and the use of alternate means to maintain continuous airborne surveillance, uninterrupted communication, and accurate navigation inputs are critical to maximize the benefit of NSW forces under DMO. Guaranteed access to communication, navigation, and data transfer networks is required for successful mission execution. Unique or novel methods are needed to facilitate tactical maneuver in contested battlespaces. High-altitude balloons (HABs) offer a potential low-cost, low-observable method to increase force projection across domains and provide the infrastructure required to support NSW tactical maneuvers. Using HABs as an ad-hoc, organic asset has the potential to bring data across multiple platforms to the ground user and maximize resources in DMO.

The Bento Box, a modular HAB bus that was designed to operate independently or integrated into a host vehicle, was conceived around an educational HAB platform designed by the Naval Postgraduate School's Space Systems Academic Group (SSAG) (Gallegos, Hansen). The integration of three payloads into the Bento Box demonstrated the modularity of the structure; one such payload is a software defined radio (SDR) reconfigured as a bent-pipe communications payload to relay video transmission signals. The study concluded with a field test of the HAB-suspended Bento Box for beyond line-of-sight (BLOS) video relay between maneuver elements.

Previous research conducted by the SSAG students demonstrated that the Ettus B205mini-i SDR can be supported on the HAB bus; this included performing CONOP feasibility testing for space-to-ground, BLOS voice communication relays in very-high frequency (VHF) with PRC-152 radios for a special operations forces (SOF) use case (Swintek, 2018). For this study, the ADALM-PLUTO SDR used for BLOS video relay (Hansen, 2022) was selected as the baseline use-case scenario to explore a CONOP of an ad-hoc communications network of HABs that could optimize the space domain to support the Navy and Marine Corps' concepts of DMO and Expeditionary Advance Base Operations (EABO). The Arctic region was selected as the primary focus of the CONOP due its harsh and extreme environment, limited access to space assets, and the growing threat of Russia and the People's Republic of China (PRC) as they pursue maritime supremacy. Proven automated HAB commercial technology was considered in constructing the CONOP, along with the decision-centric mindset of Mosaic Warfare (Williams, 2022).

Modeling and simulation efforts were conducted with System Tool Kit (STK) to evaluate the suitability and feasibility of the baseline architecture centered around DMO in the Arctic environment. Incremental testing efforts, starting with bench testing in a laboratory environment, were performed to examine the cross-link functionality of two HAB systems. Environmental testing in flight-like conditions provided confidence that the current design solution will survive and operate reliably at the desired altitudes and environments that High-Altitude Balloon Persistent OverWatch and Electronic Reconnaissance.(HAB POWER) may be tasked to operate in. Lastly, proof of concept demonstrations provided valuable insight towards the feasibility of an ad-hoc near-space architecture that can support DMO for NSW (Williams, 2022).

Findings and Conclusions

This research concluded that HABs could optimize the space domain by integrating the stratosphere with the space domain and augmenting satellite-like capabilities to the tactical and operational maritime warfighter. Specifically, adapting proven automated HAB commercial technology with the decision-centric mindset of Mosaic Warfare allows for the creation of the technological concept HAB POWER. Coverage, in terms of access time over the area of interest (AOI), was the primary figure of merit in comparing the capabilities of HAB POWER and a few low-Earth orbiting (LEO), high-inclination satellite architectures in the Arctic region. This analysis highlighted that HAB POWER could provide greater persistent coverage over an AOI for a tactical or operational user. However, by integrating HAB POWER with satellites, overall space capacity and coverage is increased, creating few gaps along a maritime route's chokepoints (Williams, 2022).

Building on a balloon flight that was conducted on the Bento Box platform in June 2021, the lessons learned from this field test were applied to improve its performance. Passive thermal control was added to the bus to improve the system's reliability in extreme temperatures, both potentially on the ground and in flight. The thermal test conducted in May 2022 validated the efficacy of the thermal control design. During this test, the Bento Box was fully integrated with both an ADALM-PLUTO SDR and an LED payload to exercise the modularity features; no issues were encountered at this stage. Finally, the CONOP was replicated on the ground as a proof of concept demonstration, where bent-pipe voice communications were achieved between two PRC1-52 ground user radios that did not have line-of-sight via two fully-integrated Bento Box systems. This demonstration highlights the feasibility, given that commercial balloon technologies are utilized, of a stratospheric solution within the DMO and EABO concept. For example, a HAB POWER relay capability would

relieve logistical and manning strain on warfighters that are operating distributed. Additionally, HAB POWER provides a reliable, redundant, first line of defense, satellite-like capability that augments the space domain from the stratosphere (Williams, 2022).

Investigation of machine learning (ML) algorithms to improve overall geolocation accuracy revealed that math-based geolocation processing continues to be more accurate than ML-derived accuracy. Specifically, for maintaining positional accuracy for targets that are no longer emitting a radio-frequency (RF) signal, Kalman filtering with a chi-squared statistical anomaly detector can accurately estimate the target location. However, it is understood that ML techniques can potentially improve accuracy or provide increased situational awareness of the RF signal itself when applied outside of the geolocation calculation, such as when the initial RF signal is collected.

Recommendations for Further Research

The results of this study indicate that small satellite technologies can be adapted for the stratospheric environment, and that a modular high-altitude balloon (HAB) system such as the Bento Box can act as a catalyst to operationalize the stratosphere. Therefore, it is recommended that commercial capabilities, such as commercial balloon systems and small satellite buses, be integrated together to achieve an ad-hoc mission architecture that can enhance Naval Special Warfare (NSW) capabilities in a degraded satellite communications (SATCOM) environment.

Further integration of an operational stratospheric system with existing and future satellite architectures, both military and commercial, will also enhance the Distributed Maritime Operations (DMO) concept. Especially as proliferated low-earth orbit (pLEO) constellations become available and are integrated into the Fleet, a near-space capability provides another layer of resilience in assured communications for the warfighter.

To successfully leverage machine learning for improved geolocation accuracy, further research is recommended to investigate methods for radio-frequency (RF) interference and identification, which will then have potential downstream effects on geolocation. If cloud technology can be leveraged in-situ, this will also have potential positive impacts on decision latency, both during the tasking-to-dissemination cycle and the kill chain overall.

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Acronyms

AOI	area of interest
BLOS	beyond-line-of-sight
CONOP	concept of operations
COTS	commercial off-the-shelf
DMO	distributed maritime operations
EABO	Expeditionary Advance Base Operations
HAB	high-altitude balloon
LEO	low-earth orbit
ML	machine learning
NPS	Naval Postgraduate School
NSW	Navy Special Warfare
pLEO	proliferated low-earth orbit
POWER	Persistent OverWatch and Electronic Reconnaissance
RF	radio frequency
SATCOM	satellite communications
SDR	software-defined radio
SOF	Special Operations Forces
STK	System Tool Kit
SSAG	Space Systems Academic Group
VHF	very-high frequency