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Proliferated LEO Architecture Enabling Beyond Line of Sight Fires (pLEO BLOS Fires)

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PROLIFERATED LEO ARCHITECTURE ENABLING BEYOND LINE-OF-SIGHT FIRES (PLEO BLOS FIRES) EXECUTIVE SUMMARY

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Project Summary
The Space Development Agency (SDA) is currently testing and fielding the National Defense Space Architecture (NDSA) which will include hundreds of Earth-orbiting satellites that gather targeting and tracking information and instantly transmit it to warfighters and weapons systems. The architecture includes seven layers: transport, tracking, custody, deterrence, navigation, battle management, and support. This project was centered on efforts towards SDA's transport layer, the layer of data routing, and communications infrastructure. Research focused on development of a space-based transport layer architecture to facilitate beyond line-of-sight (BLOS) communications in support of advanced missile detection, tracking, and long-range targeting. The primary objective of the research was to create a constellation capable of providing assured, resilient, globally persistent BLOS data and communications to warfighters in near real-time while ensuring joint force integration, functionality in degraded environments, and maintenance of low acquisition costs. Mission and system requirements were established and presented to four teams. Modeling using Systems Tool Kit (STK) was performed by each of the four teams to develop a transport layer architecture that met all requirements. An analysis of alternatives was conducted between teams to develop a single final transport architecture. Findings showed that the use of a proliferated low-Earth orbit (pLEO) architecture can benefit the warfighter by providing large throughput, globally persistent, low latency data to large numbers of users, while also maintaining protection from degradation using high-capacity inter-satellite crosslinks. This transport layer can be applied as the backbone and integrator of various space capabilities, including imagery, signals intelligence, tracking, targeting, and communications. It is recommended that this research be expanded upon and included in larger efforts such as SDA's efforts within the NDSA.

Keywords: *beyond line-of-sight, BLOS, global, low latency, Integrated Broadcast System, IBS, National Space Defense Architecture, NSDA, near real time, proliferated low-Earth orbit, pLEO, persistent, resilient, Space Development Agency, SDA, tactical data links, transport layer*

Background

The recent increase of commercial space-based assets, particularly in low-Earth orbit (LEO), has led towards the adoption of pLEO systems by the national defense industry. Proliferated LEO architectures provide more resilient, globally persistent, and low latency data relay ability, using smaller, less costly satellites than traditional architectures. SDA's system is built on the premise of a threat-driven space architecture, providing different capabilities including surveillance; tracking; targeting; alternate position, navigation, and timing; as well as global battle management support. A pLEO transport layer supports integrating, and delivering high capacity, near real-time data to forces around the world and provides passive resistance to degradation through routable inter-satellite crosslinks and an abundance of satellites, able to maintain operation through disruptive events. Active defenses such as encryption, low probability of intercept/detection, and interference resistance add to the system's security.

Compared to traditional satellite communication methods of large, complex satellites in higher geosynchronous or geostationary (GEO) orbits, LEO satellites have significantly lower latency, cost, and time for development to launch allowing pLEO constellations to be reconstituted cost-effectively every few years, rather than every few decades, meaning constellations will be able to incorporate the latest capabilities and technological improvements.

A market survey was conducted to compile data on each planned system including orbital architectures, technical details of the communications links, system capabilities, expected user experiences, market share, and timelines.

Initial work on this project involved the development and refining of a system mission statement, mission objectives, four overarching mission requirements, and 12 nested system requirements for a nominal SDA transport layer constellation. These requirements were provided to four separate teams of students, each tasked to create and model a unique architecture, proving its ability to meet all requirements, using STK and other available tools and methods.

The team architectures presented included two LEO-only architectures, one LEO architecture with high altitude balloon (HAB) augmentation, and one medium-Earth orbit and highly elliptical orbit hybrid constellation. After an analysis of alternatives between the four team architectures, a final hybrid architecture was developed using the most successful portions of each. The final architecture included a 250-satellite constellation (including 22 on-orbit spares) at 780 km altitude, 84.6-degree inclination, Ka-band downlinks, 60 GHz crosslinks, and capable of HAB augmentation.

This constellation was modeled in STK for analysis of coverage, revisit time, and communications capability at the required frequencies and data rates for downlinks, crosslinks, tactical data links, and IBS support. Coverage and revisit time using STK figures of merit confirmed a 100% persistent global coverage at all latitudes, with no less than two satellites in view at any time. STK link budget analysis showed that user downlinks were successful using Ka-band radio frequency, at a data rate of over 100 Mbps. A radio frequency crosslink of 60 GHz was able to achieve an acceptable level of error at a data rate above 10 Gbps. An analysis of a simulated Link 16 model was also shown to be readily possible with this architecture.

Findings and Conclusions

Overall, utilization of a pLEO architecture, as opposed to a small number of higher altitude satellites, as in traditional architecture, provides a robust passive defense to the degradation of the system. With multiple satellites constantly in view of any ground user, the constellation can retain an acceptable level of operational support even while a large percentage of its satellites are inoperable, due to either intentional or unintentional degradations. With the addition of inter-satellite crosslinks, a pLEO architecture such as this becomes even more resistant to degradations such as uplink jamming, making the system capable of rerouting around interruptions with limited latency increase or loss in system capacity. This analysis reinforces the viability of a pLEO architecture for uses in low latency, resilient, and critical national defense architectures.

This project contributes to pLEO architecture analysis that could be utilized in refining a transport layer for use within NDSA.

Recommendations for Further Research

Future research is recommended to expand upon proliferated low-Earth orbit architectures, filling in technical details, including those that cannot be modeled. For any architecture to be viable, further support from the tech sector will be required. Support for flexible encryption options will be sought from sources such as the National Institute of Standards and Technology (NIST). While NIST standards were explored in this study, it is recommended that an analysis of alternatives of different encryption methods be conducted to determine what standards will best fit the requirements of a national defense architecture.

Furthermore, it is recommended to conduct more research on ground infrastructure necessary to support the National Defense Space Architecture. This model lacks depth in the ground segment and more modeling may optimize ground control stations and reduce program costs. How many ground stations are needed? Where should ground stations be located? What are the policies required to place ground stations outside of the United States?

More research should also be conducted on autonomous systems for command and control (C2). While this research focused on utilizing the Defense Advanced Research Projects Agency's Pit Boss program for proliferated architecture C2, other options were not analyzed. Does Pit Boss satisfy the requirements best? Are there other options available for autonomous C2 of satellite systems? How do these other autonomous systems compare?

This research was not free from limitations. Computing and processing power available limited analysis of the modeled architecture. Only a handful of sensors, control links, crosslinks, downlinks, ground stations, and users were modeled with the limited power available. Scenarios were additionally analyzed for short durations of time. It is recommended this model be fully built out in a more powerful computing environment, to accommodate a full-scale model with a complete set of satellites, crosslinks, ground stations, and user terminals. This will provide a more realistic model for analysis. Due to the scenario constraints, no analysis was completed to observe long-term effects. It is recommended to conduct an analysis of this model for the entire service life of the spacecrafts to observe perturbations and provide vital insight into station keeping, deorbit timelines, and debris mitigation.

Finally, while this model was created to fit our series of requirements, it has not been fine-tuned; it may not be the most efficient architecture solution and may not be able to meet further undeveloped requirements. It is recommended to look at alternative iterations of proliferated transport architecture for comparison. While four methods were looked at in this study, an endless number of architecture configurations could potentially be utilized. How would this architecture benefit from the use of multiple shells? What other altitudes can be used and what are their benefits? What other inclinations can be used for this architecture? Is there a minimum viable number of satellites to support transport needs or a maximum over which little additional gain is seen?

Acronyms

BLOS	beyond line-of-sight
C2	command and control
DARPA	Defense Advanced Research Projects Agency
GEO	geosynchronous
HAB	high altitude balloon
LEO	low-Earth orbit
NDSA	National Defense Space Architecture
NIST	National Institute of Standards and Technology
pLEO	proliferated low-Earth orbit
SDA	Space Development Agency

STK	Systems Took Kit