IAF SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations - IAF SPACE EXPLORATION SYMPOSIUM (IP)

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# HYBRID RF-OPTICAL COMMUNICATION SYSTEMS FOR HIGH-GAIN DATA TRANSMISSION IN ASTEROID SAMPLE RETURN MISSIONS

**Abstract**

This research considers the design and implementation of hybrid communications systems combining radio-frequency (RF) and optical modalities for high-gain transmission of data in asteroid sample retrieval missions. In such cases, establishment of reliable and efficient communications is critical in view of significant distance and restricted availability of power. The specific requirements of such a mission include long propagation times, budgeted communications links with restrictions, and stringent Size, Weight, and Power (SWaP) constraints with regard to spacecraft payload. There is, therefore, a need for an RF-optical integration scheme taking full advantage of complementary strengths of both modalities: RF communications for reliable command and control links over long distance, and high-data-rate downlinks for scientific instruments, and for similar high-data-rate downlinks for scientific payload through optical communications. The considered hybrid scheme involves a dual-mode transceiver, capable of dynamically switching between RF and optical communications according to current mission phases, involved distance, and availability of power. In the optical part, a high-efficiency laser communications terminal with an adaptive-optical module is utilized for minimizing atmospheric perturbations and pointing errors. In the RF part, sophisticated modulations, including Quadrature Amplitude Modulation (QAM) and Low-Density Parity-Check (LDPC) codes, are utilized for efficient use of spectra and for assuring communications link reliability. The principal contribution of this work is in developing an efficient algorithm for real-time dynamic optimization of radio frequency (RF) and optical communications, with consideration for channel conditions, spacecraft orientation, and mission requirements. In addition, the system proves resistant to transient occlusions in the optical channel, such as can occur with obstruction produced by asteroids, and can dynamically adapt to channel and spacecraft orientation fluctuations. The viability of the proposed system is supported through thorough simulations with realistic deep-space

laser signal transmission, spacecraft, and ground station models. In addition, in this work, an analysis of key factors, such as laser beam divergence, aperture diameters, and pointing accuracy, is performed, providing guidance for future development programs. The work sets a basis for future communications strategies applicable to future potential asteroid sample return missions, allowing for efficient delivery of high volumes of scientific information and for reliable establishment of critical command and telemetry links. In future work, experimental demonstrations and evaluations will include multi-hop relay scenarios, with a view to extending range of hybrid RF-optical communications to deeper regions of space.