Performance Analysis and Comparison of Clustered and Linearly Dispersed Optical Deep Space Networks

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The primary objective of this paper is to compare the operational pros and cons and performance factors of two primary baseline architectures for Optical Deep Space Network (ODSN), namely the Linearly Dispersed Optical Subnet (LDOS) and Clustered Optical Subnet. These two major baseline architectures have previously been compared from various perspectives, in the 1994 Ground Based Advanced Technology Study (GBATS) report. Yet, since then advances in mirror technology, adaptive optics, aberration correction methods, optical phase modulators, wave front sensors, segment edge sensors, miniature mirror actuators, acquisition, pointing and tracking, and optical arraying techniques have occurred that offer improved system performance over those proposed in GBATS. Additionally, continued research has led to a better understanding of perceived operational constrains such as elevation angle, minimum required data rate, transponder requirements, and availability of the network due to weather. On the other hand, advances in light-weight mirror technology made during the development of the James Webb Space Telescope (JWST) have attracted attention to optical relay telescopes. Since GBATS the volume of literature has almost equally increased many folds for both 10-m ground telescopes as well as large, i.e., beyond 6-m space-based telescopes, and mission mirrors. The prime mission of an optical deep space network is somewhat different from individual astronomical observation telescopes. While an astronomical telescope requires high angular resolution near diffraction-limited performance for imaging, the performance of an optical communication telescope can be limited by the sky background and stray light during daytime operation.

The key objective of an optical communication telescope is to collect as much signal transmitted from the spacecraft, which makes the accurate choice of telescope network architecture as well as the size of the field of view a challenging task. For optical communications the metric is signal-to-noise-ratio (SNR) and for deep space links during nighttime operation the telescope surface figure is not as critical as it is for imaging telescopes. However, during the daytime background sky and scatter from telescope surface degrade the SNR and the techniques of adaptive optics, which were originally developed for correction of atmospheric-induced, or thermal-induced wave front aberration can enable narrowing the field of view and thereby enhance the SNR. Therefore, despite the differences, a telescope element of the deep space optical network can very well be analogous in many respects to an astronomical telescope, such as Hobby-Eberly Telescope (HET). There are major trade offs between space-based telescopes versus the ground-based telescopes. To say the least, while the first one is limited by launch cost, the latter is constrained by the gravitational and environmental effects. As an example, finding a suitable site for a large telescope that fits all the constrains in terms of altitude, weather patterns, network operation concept, stray light conditions, optimal distance from the other telescope elements of the network with ease of access to network facility is a challenge by itself.

In this paper, recent technological developments in large telescopes, i.e., 5 meters and beyond as related to deep space optical communication network will be addressed. Specifically, we shall investigate the operational and performance considerations of an LDOS and COS network. Hybrid combinations will also be discussed as well. The hybrid architecture may include combination of relay networks with some ground-based telescopes. Alternatively, making use of an array of smaller, e.g., 5 m telescopes versus 10 m aperture per individual site will also be addressed.