An Earth-to-Deep-Space Optical Communications System With Adaptive Tilt and Scintillation Correction Using Near-Earth Relay Mirrors [1]

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Optical telecommunication will be the next technology for wide-band Earth/space communication. Uncompensated propagation through the Earth's atmosphere (e.g., scintillation and wavefront tilt) fundamentally degrade communication to distant spacecraft, however. The situation is particularly acute for very long distance (e.g., earth-to-deep-space) uplinks. We proposed a system providing essentially perfect tilt and scintillation correction [1]. Our system uses an orbiting mirror with a downward-directed onboard reference laser. Adaptive optics on the ground measures tilt/scintillation using the reference and preprocess the uplink communications beam such that it arrives undistorted at the orbiting mirror; the beam is there redirected to a distant spacecraft. The system requires a space platform providing accurate, dynamic beam aiming via a flat mirror ~2 meters in size. The requirements are stringent but not inconsistent with current and near-future technologies [2].

Astronomical imaging correction schemes [e.g., 3] are not generally applicable to the uplink optical telecommunications problem: (a) optical downlink from the spacecraft itself cannot be used as an artificial guide star (AGS) reference (too weak and coming from the wrong direction due to aberration), (b) bright natural stars near the uplink direction are not generally available, (c) monochromatic AGSs produced by a laser co-located with the telescope cannot measure tilt (tilt is common to both the beam propagating up and to the AGS light propagating down), (d) two or more AGSs produced by transmitters physically separated from the main telescope can, in suitable circumstances, estimate tilt in the uplink direction but there are practical difficulties [4], and (e) polychromatic artificial guide stars, exploiting atmospheric dispersion to infer tilt, are challenging in terms of required laser power [5].

A fundamentally different way for deep-space communications through atmospheric distortions is to locate a mirror in Earth orbit. A reference beam, produced by a small onboard laser, provides the information a ground-based adaptive optics system needs to correct distortions and deliver a diffraction-limited beam to the orbiting mirror. (The reference source is slightly separated from the mirror to allow for mirror/ground-station relative motion. Modest reference source power and small optics are sufficient for ~millisecond atmospheric corrections.) The ~2 meter mirror then relays the corrected uplink communications beam to the spacecraft. For accurate beam delivery, control points defining mirror surface must orient the mirror to about a microradian. For some geometries intermediate relay to a second orbiting mirror may be useful. This system solves the main problems: the adaptive optics reference source is above the atmosphere, tilt is determined from a wave making only one passage through the troposphere, and active optics can be used to produce a diffraction-limited communications beam at the mirror, which is redirected to the spacecraft without distortion. This beam-relay-in-space technique can also be used for optical communications between different Earth stations.

Acknowledgments

The research described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA

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