NASA's Advanced Communications and Navigation Program Recommendation for Future Research in Free-Space Optical Communications

Most free-space optical communication (FSOC) systems developed to date have been for delivering data at very high rates over very narrow beams to single users. However, FSOC systems are appealing for serving multiple users at lower data rates due to the potential reduction in size, weight, power (SWAP) and cost as compared to RF systems, due to the factor of 100,000 reduction in the wavelength of the signals. For example, NASA's current Tracking and Data Relay Satellites (TDRS) in GEO include an S-band (2 GHz) RF phased array that can support many simultaneous users at kilobit-per-second data rates (formally known as "multiple access" or MA). However this array is 2 x 2 meters in size and requires significant power, not only for transmission but for adjusting the phase between the array elements. An Optical MA system could surely be much smaller, consume less power, and potentially offer more bandwidth (up to megabit-per-second rates). Conventional approaches have suggested arrays of individually-addressable detectors behind wide-field optics (which could be ~ 10 cm diameter), however, the advent of integrated photonics, plasmonic waveguides, and other technologies [1] may offer even more elegant and efficient solutions to this problem, both for reception and transmission. NASA recommends this area for further study. The ideal limiting case of such a system would be an optical omni-directional antenna which could be used to recover a tumbling or disoriented spacecraft, again with the understanding that the data rate may be extremely low. Again, the benefit could be a reduction in size and weight while possibly leveraging traditional, narrow-beamed (and higher gain) FSOC systems as the remote transmitter attempting to recover the spacecraft.

An additional area of interest for NASA is the development of alternative approaches to compensate for the atmosphere to allow for high-rate (100 Gbps), phase-modulated communications. NASA currently applies a traditional adaptive optics (AO) approach to compensate for atmospheric phase distortion to couple signals into single-mode optical fibers (SMF), which is required for phase-sensitive receivers. However, these systems are complicated, expensive, and introduce link losses as some of the signal is required to go to the wave front sensor. Digital coherent combining from multiple apertures [2] (where each separate aperture is smaller than the atmospheric coherence length, or Fried Parameter) and other digital techniques being developed for the nascent field of spatial-mode division multiplexing (SDM) (as proposed by Professor Kahn at the Workshop) are of interest for downlinks. Atmospheric compensation for high-rate, phase-modulated uplinks are even more challenging for traditional AO techniques due to differences in the isoplanatic angle (due to point-ahead) between the sensed downlink and a compensated uplink, requiring new approaches for this scenario as well.

To summarize, NASA's FSOC research interests are:

1. New technologies to allow for optical "multiple-user access" (MA) and ideally optical omni-directional antennas;
2. New technologies to compensate for atmospheric effects on optical downlinks,
3. New technologies to compensate for coherent high-bandwidth uplinks

[1] Peyronel, T., K. J. Quirk, S. C. Wang, and T. G. Tiecke. "Luminescent detector for free-space optical communication." *Optica* 3, no. 7 (2016): 787-792.

[2] Geisler, D. J., Yarnall, T. M., Stevens, M. L., Schieler, C. M., Robinson, B. S., & Hamilton, S. A. (2016). Multi-aperture digital coherent combining for free-space optical communication receivers. Optics express, 24(12), 12661-12671.