Laser Telemetry from Space

Joss Bland-Hawthorn

Anglo-Australian Observatory, Epping, NSW, 2121 Australia

Alex Harwit

Transparent Networks, Santa Clara, CA 95050, USA

Martin Harwit

511 H st., SW, Washington, DC 20024; also Cornell University

A challenge to earth-viewing satellites and astronomical space stations today is the enormous rise in projected data rates. Increasingly large detector arrays often with many millions of pixels are in common use. These arrays have exhibited progressively higher sensitivities and dynamic ranges, that have enabled exquisitely high spectral, spatial, or time resolution. Space missions now on the drawing boards will gather data at rates of several gigabits per second (Gbps) (1). The accumulated information will need to be telemetered to ground in brief intervals to permit available ground stations to sequentially interrogate an armada of spacecraft in different orbits in the course of a day. Downloading data during such brief sessions will require telemetry capable of transmitting at rates of the order of 100 Gbps. But current telemetry systems are orders of magnitude too slow to accomplish this task.

To sidestep this communications problem, many observers have placed their hopes on onboard data compression, a technique that culls out significant data for transmission to ground and discards the rest. Data compression assumes that the characteristics of a data stream are known; evidence for unanticipated, surprising new natural phenomena may be inadvertently discarded if the data does not fit into the expected mold. Also, where observations are marred by unpredictable noise spikes, these spikes need to be identified, characterized, and their memory effect on detector sensitivity, amplifier gain, and other instrumental parameters clearly defined (2). Reliable use of such data is possible only if the full data set is transmitted to ground.

Unless a solution to this mounting telecommunications problem is soon found, limited telemetry rates will become a certain bottleneck in the decade ahead. Given the importance to the astrophysical, geophysical, meteorological, climatological, and earth-resource communities, space agencies world-wide should invest substantial resources to rapidly develop the necessary telecommunications techniques and infrastructure.

The bottleneck in existing radio-telemetry systems is available bandwidth. Data transmission rates are directly proportional to transmission bandwidth, which never exceeds a small fraction of the electromagnetic “carrier” wave frequency that the transmitted data modulates. Telemetry systems now are reaching toward bandwidths of order 8 GHz; but bandwidth cannot dramatically increase unless carrier frequencies increase proportionally. Current international allocations for transmission between Earth and space range only up to 275 GHz (3) because atmospheric gases strongly absorb above this frequency and prevent transmission from space to ground. To employ higher carrier frequencies a leap of a factor of a thousand is needed to reach near-infrared frequencies, where the atmosphere again transmits well.

Fortunately, much of the technology required for near-infrared telemetry has already been developed for fiber telecommunications particularly in the 1500-1600 nm band (4). The European Space Agency (ESA) has recently demonstrated near-infrared laser communication between the SPOT-4 and Artemis orbiting satellites (5). Initial tests used experimental data rates of only 50 Mbps. This rate can be increased by factors of thousands without basic changes of principle, but will require increased signal power; a suitable transmitter; and adequate onboard memory. Several well-separated mountain-top receiving stations around the globe are also needed to receive transmissions from spacecraft in various orbits.

Ground receiving stations are simply large optical telescopes, which we know how to build. On high mountain tops, the atmosphere transmits signals from space to ground with a satisfactory efficiency of $> 70\%$ at 1500-1600 nm. Signal power onboard spacecraft can be provided by existing laser diodes amplified by Erbium Doped

Fiber Amplifiers (EDFA) or Raman amplifiers, both in extensive use at 1550 nm in the telecommunications industry (6). To obtain sufficient bandwidth, Dense Wavelength-Division Multiplexing (DWDM), a widely used technique in the telecommunications industry, can be employed (7). The spacecraft transmitter can be a 1-meter-class telescope with high pointing accuracy and adaptive optics to assure a properly collimated beam. The only component not readily available is the onboard memory required to store up to several days' worth of collected data.

A data gathering rate of 1 Gbps accumulates $\sim 10^{14}$ bits of information in the course of a day. Commercially available solid state memories store up to $\sim$ 128 gigabytes of memory, or 10^{12} bits. If current growth rates are sustained, the required factor of $\sim$ 100 increase in memory capacity will become commercially available within 10 to 15 years.

If we start serious work towards a functioning near-infrared telemetry system today, an effective system can be available in 10 - 15 years to fully service missions now on the drawing boards. The lead must come from the scientific community. The U. S. National Academy of Sciences has recognized the problem (8), but energetic action will be required to prevent a data transmission bottleneck from reaching crisis proportions.

Because the fiber-optics communications industry already provides most of the individual components required for near-infrared laser telemetry, and components not yet available should come on the market in the decade ahead, work towards a near-infrared telemetry system carries little risk and will rapidly pay for itself in the efficiency with which data can be gathered and transmitted. Meteorology, climatological observations, oceanography, geophysical studies, planetary exploration, and astrophysics will all benefit. However, progress will come about only with the allocation of sufficient resources by NASA and ESA – the two lead agencies in the field – and the focused attention of the scientific community.

Acknowledgment

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References and Notes

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