Engineering xxx (xxxx) xxx

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

News & Highlights

NASA Satellite Sets Blistering Optical Communication Speed Record

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In April 2023, a satellite orbiting approximately 500 km above Earth's surface delivered terabytes of data at record-breaking rates of up to 200 Gb•s^{-1}—more than 100 times faster than the fastest internet speeds in most cities—via an optical communication link to a ground-based receiver 95 km north of Los Angeles, CA, USA [1]. At more than 1000 times faster than the radiofrequency (RF) links traditionally used for satellite communication, this is the highest data rate ever achieved for a space-to-ground optical transmission [1]. Operated by the US National Aeronautics and Space Administration (NASA), the tissue box-sized TBIRD (short for terabyte infrared delivery) is just one of the agency's novel optical communications platforms and a preview of what is to come as numerous countries and private companies work on developing technology to increase communications bandwidth in space.

Researchers at the Lincoln Laboratory at the Massachusetts Institute of Technology (MIT) (Lexington, MA, USA) designed TBIRD to provide unprecedented transmission speeds to support NASA science missions at a low cost. Carried aboard a CubeSat satellite weighing approximately 11 kg, TBIRD features components developed initially for terrestrial fiber-optic networks, including a high-rate optical modem, a large high-speed storage drive, and an optical signal amplifier (Fig. 1) [2].

"With TBIRD, NASA has kicked opened the door and shown it is possible to get faster-than-internet communications from space," said Rainer Martini, an associate professor of physics at Stevens Institute of Technology in Hoboken, NJ, USA, who specializes in space optical communications. "It works very well, and cheaply."

Since the 1950s, radio waves have transmitted most space communications via the Deep Space Network, a global array of antennas capable of sending and receiving information [3]. In subsequent decades, space-based science instruments have become so sophisticated that they routinely generate more data than can be returned to Earth over standard space-to-ground RF communications links. There is even an instrument on the International Space Station (ISS)—the Hyper-spectral Imager Suite—whose data is sent back to Earth via storage drives ferried on cargo ships due to limitations on the station's downlink rates [4]. "When you consider the instruments that can capture very high-quality data we now have in space, the problem has become how do we get the data back to Earth," Martini said.

Compared to radio waves, the lasers used in optical communications can transmit data at much higher frequencies, allowing more to be packed into each transmission. In addition to boosting speed, optical communications systems can be made smaller, lighter, and less power-hungry than RF transmission devices. Unlike RF signals, however, optical signals can be distorted by atmospheric effects and weather conditions, resulting in data loss. To overcome this challenge, TBIRD transmits its information to an optical ground station located at the NASA Jet Propulsion Laboratory (JPL)'s Table Mountain Observatory (TMO) near Wrightwood, CA, USA, chosen for its minimal cloud cover [5]. TMO leverages a one-meter telescope as well as adaptive optics to correct for distortions of the optical downlink signal caused by atmospheric optical turbulence. Because data transmission is only possible when TBIRD, which is parked in low Earth orbit (LEO), is in line of sight with a ground station, the satellite is limited to beaming down information in roughly 5-minute chunks. But at 200 Gb•s^{-1}, that is more than 2 Tb of data—roughly as much as 1000 high-definition movies—for each pass [1].

It is not enough, however, to be in line of sight. Unlike RF communications, optical communications require that laser beams be aimed precisely at their receivers on the ground. "When you are working with radio waves, you are transmitting big beams at 7 GHz, and you can just point everything in the general direction, and it works," Martini said. "When you go to a laser transmitting at higher data rates, around 40 GHz, the beam gets much narrower, and it becomes a headache to track."

Previous space-based laser communications devices have often accomplished their precision aiming by mounting the laser on a gimbal. Due to TBIRD's small size, however, it instead relies on error signals it receives from a laser beamed up from its ground station to correct its orientation [1].

TBIRD's design supports multiple channels through wavelength separation, with its record-breaking 200 Gb•s^{-1} downlink accomplished by combining two 100 Gb•s^{-1} channels. In future iterations, the satellite can be configured to combine more channels for even higher rates [1]. Hamid Hemmati, vice president and chief technology officer at the Carlsbad, CA, USA-based company Viasat, which provides high-speed satellite broadband communication services and secure networking systems to commercial and military markets, said he anticipates technology improvements across the sector will lead to even higher speeds. "Likely within a decade, we can expect satellite optical communications to be in the one terabyte per second regime."

https://doi.org/10.1016/j.eng.2024.02.004
2095-8099/

Please cite this article as: C. Palmer, NASA Satellite Sets Blistering Optical Communication Speed Record, Engineering, https://doi.org/10.1016/j.eng.2024.02.004

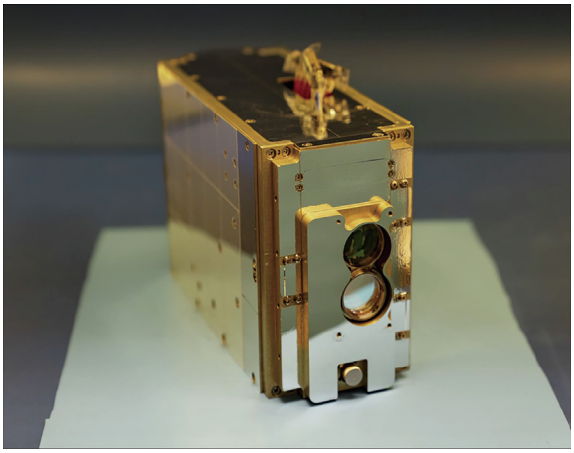

Fig. 1. Launched into low Earth orbit in 2022, the tissue box-sized, 2.5 kg TBIRD communications system aboard a CubeSat satellite is comprised of an off-the-shelf modem, storage drive, and signal amplifier. The setup recently transmitted terabytes of data at a record speed of 200 Gb•s^{-1} via an optical communication link to a ground-based receiver. Credit: Lincoln Laboratory (public domain).

Fig. 2. The DSOC laser transceiver, encased in its tubelike sunshade protruding from the side of the Psyche spacecraft, set a record in 2023 for the longest optical data transmission at 1.6×10^7 km. Credit: NASA/JPL-Caltech (public domain).

For now, the MIT team is working to extend TBIRD's reach as far away as the moon to support future missions, such as NASA's crewed lunar flyby mission Artemis II, with transmission rates in the 1 to 5 Gb•s^{-1} range [1]. The TBIRD technology may also find use on the ground in building-to-building communications or across inhospitable terrain where laying fiber systems would be cost-prohibitive [1]. "I would like to see something like this used to transmit data from Mars," said Martini, noting the 2 Mb•s^{-1} transmission rate of the satellite conveying data from the Mars Curiosity rover. "Right now, the rover's operators must be very careful about deciding what data to transmit because you cannot send all of it."

TBIRD is not the only NASA-sponsored technology for space-to-ground optical communications. In December 2021, the agency launched the Laser Communications Relay Demonstration (LCRD), a two-way optical communications system that orbits 35 406 km above Earth and transmits data at up to 1.24 Gb•s^{-1} [6]. LCRD will relay data from the Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T) that was installed on the ISS in October 2023. The refrigerator-sized ILLUMA-T, also built by MIT, will gather information from experiments conducted aboard the space station and send the data to LCRD, which will then relay the information down to TMO and another ground station in Haleakalā, Hawaii [5]. "It was challenging, but we were able to support two different optical ground operations, LCRD and TBIRD, using the same optical table," said Sabino Piazzolla, the senior engineer at JPL who led the team that outfitted the TMO to receive transmissions from TBIRD.

In addition, NASA has developed the Orion Artemis II Optical Communications System, or O2O, which will return high-resolution images and video of the lunar surface back to Earth at 260 Mb•s^{-1} [6]. O2O will also be able to send and receive flight plans, voice messages, and other communications between the Orion spacecraft and NASA mission control on Earth during the ten-day mission [7].

Another NASA optical communications effort is the Deep Space Optical Communications (DSOC) experiment aboard the Psyche spacecraft (Fig. 2), which is headed for a 2029 rendezvous with the metal-rich asteroid 16 Psyche some 3.6×10^9 km from Earth [8]. DSOC is comprised of an infrared laser and a photon-counting camera attached to a 22 cm telescope. "DSOC recently successfully delivered data at up to 260 Mb•s^{-1} to its optical ground station," said Piazzolla of a transmission across 1.6×10^7 km of space. "To date, that is the furthest an optical communication system has relayed data."

The European Union, Japan, China, and private companies also have, or are developing, optical communications platforms for space. The European Space Agency's European Data Relay System (EDRS) connects LEO satellites with two satellites in geosynchronous orbit (GEO), which then relay data at 1.8 Gb•s^{-1} down to European ground stations that they are always situated above. This arrangement helps avoid the time delay that would otherwise occur when LEO satellites must wait for a line of sight with their ground stations [9]. Japan's Laser Utilizing Communication System (LUCAS) satellite also sits in GEO and transmits bidirectional laser communications to and from a ground station at 1.8 Gb•s^{-1} [10].

The Chinese company Chang Guang Satellite Technology Co., Ltd. (Changchun, Jilin, China) has successfully transmitted remote sensing images at a rate of 10 Gb•s^{-1} by laser from a Jilin-1 satellite to a vehicle-mounted ground station moving at high speeds [11]. The company has plans to increase the transmission rate to 40–100 Gb•s^{-1}. It is also working on inter-satellite optical links among its more than 100 satellites. These links will help overcome China's relative lack of ground stations.

Following a similar strategy, Amazon's Project Kuiper (Redmond, WA, USA) is working with the US Department of Defense on the possibility of using laser communications terminals on the company's internet satellites to transfer data from remote-sensing satellites directly into the military's mesh network in LEO [12]. The plan would have the Kuiper satellites relay data at high speeds from commercial imaging satellites to military users on the ground. Likewise, SpaceX claims similar capabilities for its Starlink constellation, with more than 8000 space lasers claimed to be installed across its satellite network that can transfer data at a rate of 100 Gb•s^{-1} on each link [13].

"In general, the benefit of large satellite constellations connected with optical communications is that, instead of needing to have a large number of ground stations, data can hop from satellite to satellite to satellite and then get downlinked," Hemmati said.

Kuiper, Starlink, and Viasat are also among 11 organizations selected by the US Defense Advanced Research Projects Agency (DARPA) to help develop technology and technical standards to create an "internet of LEO satellites" [14]. Such a network would allow seamless communication among military, government, and commercial satellite constellations that currently are unable to talk with each other. Other high-profile technology companies developing optical communications technology for space or incorporating such technology into their next generation of satellites include

Lockheed Martin [15], Mitsubishi [16], Northrup Grumman [15], and Sony [17]

"Laser technology is just another tool in the communication toolbox," Hemmati said. "It is not going to replace RF communication. However, if you need ultra-high capacity, above 10 Gb•s^{-1}, on a single beam, and you can tolerate the cloud outage, then optical communications can be a very powerful tool. If you want to scale your capacity to hundreds of gigabits per second or multi-terabytes per second, it is the only way to go."

And the payoff? "If you have no bandwidth restrictions, you are talking about a completely different way of doing science," said Martini. "You can have all the sensors transmitting simultaneously, giving you a completely different ability to understand what is going on out there."

References

[1] Choi CQ. NASA's laser link boasts record-breaking 200-Gb/s speed [Internet]. New York City: IEEE Spectrum; 2023 May 29 [cited 2023 Dec 6]. Available from: https://spectrum.ieee.org/laser-communicationsc.

[2] Tantillo A. Communications system achieves fastest laser link from space yet [Internet]. Cambridge: Massachusetts Institute of Technology; 2022 Nov 30 [cited 2023 Dec 6]. Available from: https://news.mit.edu/2022/communications-system-achieves-fastest-laser-link-space-yet-1130.

[3] Woodall T. 60 years of moonshots, made possible by the Deep Space Network [Internet]. New York City: Recurrent; 2022 Nov 30 [cited 2023 Dec 6]. Available from: https://www.popsci.com/science/nasa-moon-deep-space-network/.

[4] Hyper-spectral Imager Suite [Internet]. Tokyo: Japan Space Systems; [cited 2023 Dec 6]. Available from: https://www.jspacesystems.or.jp/en/project/observation/hisui/.

[5] Murphy K. What's next: the future of NASA's laser communications [Internet]. Washington, DC: National Aeronautics and Space Administration; 2022 Aug 11 [cited 2023 Dec 6]. Available from: https://www.nasa.gov/directorates/somd/space-communications-navigation-program/whats-next-the-future-of-nasas-laser-communications/.

[6] Hitchens T. Signaling across the cosmos: optical communications are poised for takeoff during NASA's "Decade of Light" [Internet]. Bellingham: SPIE; 2022 Nov 1 [cited 2023 Dec 6]. Available from: https://spie.org/news/photonics-focus/novdec-2022/signaling-across-the-cosmos?SSO=1.

[7] Strickland A. Lasers on Artemis II will share high-definition video of the moon [Internet]. Atlanta: Cable News Network; 2023 May 9 [cited 2023 Dec 6]. Available from: https://www.cnn.com/2023/05/09/world/artemis-2-laser-communications-scn/index.html.

[8] Strickland A. 'First light': NASA receives laser-beamed message from 10 million miles away [Internet]. Atlanta: Cable News Network; 2023 Nov 24 [cited 2023 Dec 11]. Available from: https://www.cnn.com/2023/11/24/world/nasa-psyche-dsoc-first-light-scn/index.html.

[9] Calzolaio D, Curreli F, Duncan J, Moorhouse A, Perez G, Voegt S. EDRS-C—the second node of the European Data Relay System is in orbit. Acta Astronaut 2020;177:537–44.

[10] Howell E. Japan launches advanced relay satellite with laser communications tech into orbit [Internet]. New York City: Future US, Inc.; 2020 Nov 30 [cited 2023 Dec 6]. Available from: https://www.space.com/jaxa-launches-laser-communications-satellite.

[11] McFadden C. China's satellite achieves 10 Gbps space-to-ground laser data transfer [Internet]. New York City: Interesting Engineering, Inc.; 2023 Oct 17 [cited 2023 Dec 6]. Available from: https://interestingengineering.com/innovation/china-10-gbps-laser-data-transfer.

[12] Erwin S. Amazon to link Kuiper satellites to DoD's mesh network in space [Internet]. Alexandria: SpaceNews; 2022 Oct 14 [cited 2023 Dec 6]. Available from: https://spacenews.com/amazon-to-link-kuiper-satellites-to-dods-mesh-network-in-space/.

[13] Paleja A. Starlink launches V2 mini-satellites with 'space lasers' [Internet]. New York City: Interesting Engineering, Inc.; 2023 Oct 3 [cited 2023 Dec 17]. Available from: https://interestingengineering.com/innovation/starlink-v2-satellites-space-lasers.

[14] Erwin S. DARPA selects companies for inter-satellite laser communications project [Internet]. Alexandria: SpaceNews; 2022 Aug 10 [cited 2023 Dec 6]. Available from: https://spacenews.com/darpa-selects-companies-for-inter-satellite-laser-communications-project/.

[15] Erwin S. Space Development Agency awards contracts to Lockheed Martin, Northrop Grumman for 72 satellites [Internet]. Alexandria: SpaceNews; 2023 Aug 21 [cited 2023 Dec 6]. Available from: https://spacenews.com/space-development-agency-awards-1-5-billion-to-lockheed-martin-and-northrop-grumman-for-72-satellites/.

[16] Mitsubishi claims breakthrough for laser communication in space [Internet]. Cardiff: SPIE Europe; 2022 Jun 1 [cited 2023 Dec 6]. Available from: https://optics.org/news/13/6/1.

[17] Rainbow J. Sony launches space laser communications business [Internet]. Alexandria: SpaceNews; 2022 Jun 3 [cited 2023 Dec 6]. Available from: https://spacenews.com/sony-launches-space-laser-communications-business/.