The Scanning the Literature column provides concise summaries of selected papers that have recently been published in the field of networking. Each summary describes the paper's main idea, methodology, and technical contributions. The purpose of the column is to bring the state of the art of networking research to readers of *IEEE Network*. Authors are also welcome to recommend their recently published work to the column, and papers with novel ideas, solid work, and significant contributions to the field are especially appreciated. Authors wishing to have their papers presented in the column should contact the Editor.

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Deep space exploration such as lunar and Mars exploration is currently becoming a popular international space activity. Deep space communication is the cornerstone technique that is responsible for Earth–spacecraft and inter-spacecraft information exchange. Due to the long distance and harsh working environment, the design requirements for communication systems in deep space scenarios are much higher than those for their traditional ground-to-ground counterparts. The column in this issue tries to present the state of the art of deep space communication from an academic perspective. We pay special attention to RF/FSO systems, reliable deep space vehicle communication, dynamic link budget design in satellite communications, deep space network queuing antenna, high-accuracy navigation for deep space probes, and the Internet of Deep Space Things (IoDST).

Free space optical (FSO) communications is becoming increasingly mature for the deep space communication scenario, where the advantages include high throughput, and low power consumption and cost compared to conventional radio frequency (RF) communications. However, the quality of the link degrades when the signal is transmitted between the Earth station and the deep space probe due to the path loss and misalignment errors caused by dynamic wind loads and weak vibration in the transmitter and receiver. Moreover, the FSO link is vulnerable to atmospheric turbulence due to the fluctuations in the refractive index. To address those challenges, G. Xu *et al.* propose a dual-hop mixed RF/FSO system in the following paper.

Mixed RF/FSO Deep Space Communication System Under Solar Scintillation Effect

Guanjun Xu and Qinyu Zhang, *IEEE Trans. Aerospace and Electronic Systems*, vol. 57, no. 5, pp. 3237–51, Oct. 2021.

In this paper, a new paradigm with the dual-hop mixed RF/FSO system for the deep space communications link during a superior solar conjunction is proposed. To verify effectiveness of the system, an RF link between the Earth and a geosynchronous orbit relay satellite and an FSO link between the satellite and a deep space probe is evaluated for the first time. The results suggest that the performance of the proposed deep space mixed RF/FSO system is vulnerable to some key parameters, but it still outperforms the pure RF or FSO counterparts.

While the reliable transmission service in current studies is proposed under an assumption that the communication link is consistently available, the link outage or disruption is factually inevitable in space communications, especially in deep-space vehicle communications due to spacecraft/planet rotations, interplanetary scintillation, or solar wind. To address the issue, L. Yang *et al.* present a new retransmission approach, where a proactive retransmission phase is followed by a retransmission phase.

Hybrid Retransmissions of Bundle Protocol for Reliable Deep-Space Vehicle Communications in Presence of Link Disruption

Lei Yang, Ruhai Wang, Yu Zhou, Xingya Liu, Kanglian Zhao, and Scott C. Burleigh, *IEEE Trans. Vehic. Tech.*, vol. 70, no. 5, pp. 4968–83, May 2021.

In this paper, the authors propose the bundle protocol (BP) for highly reliable data delivery in deep-space vehicle communications in the presence of an unpredictable or random link disruption. The basic idea is to use the hybrid proactive and reactive retransmission mechanisms during data transfer. Analytical models are built in various transmission cases to study the link disruption impact on reliable transmission of BP, with focus on the number of failed transmission attempts, file delivery time, and goodput performance normalized with respect to the total amount of data sent. The models are validated by the file transfer experiment over a PC-based testbed. They also present a performance comparison between the proposed approach and the existing transmission approach with respect to transmission reliability.

The crux of deep space communication link budget design is that we have to know the radio propagation characteristics of the atmosphere in the first place. Such characteristics (i.e., atmospheric attenuation and brightness temperature), especially at Ka-band and above (which are frequencies currently being investigated by several space and deep-space missions), however, can be extremely variable and difficult to predict with classical models based on climatological statistics (successfully used at lower frequencies such as the X-band). We could resort to weather-forecast-based link budget design techniques, which allow dynamically adapting the satellite link on the basis of specific atmospheric conditions predicted and expected during each satellite-to-Earth transmission period (called pass). The authors develop the Radio Meteorological Operation Planner (RMOP): a weather-forecast-based link budget design model for the dynamical optimization of satellite links operating at Ka band exploiting pass-specific atmospheric statistics. M. Biscarini *et al.* describe and validate the weather-forecast based Radio Meteorological Operation Planner model using data from a deep-space satellite mission in the following paper.

Dynamical Link Budget in Satellite Communications at Ka-Band: Testing Radiometeorological Forecasts with Hayabusa2 Deep-Space Mission Support Data

M. Biscarini, K. De Sanctis, S. Di Fabio, M. Montagna, L. Milani, Y. Tsuda, and F. S. Marzano, *IEEE Trans. Wireless Commun.*, vol. 21, no. 6, pp. 3935–50, June 2022.

According to this paper, for the first time, actual received Ka-band data from a deep-space satellite mission (the Hayabusa2 mission from JAXA and supported by ESA) were available for operational tests. RMOP-predicted link budget parameters were delivered in real time before each scheduled satellite transmission period. After each transmission, received data measured by the ground stations were exploited for the RMOP validation. The data volume actually received (transmitted and lost) by Hayabusa2 was compared with what would have been obtained if the transmission had been configured according to RMOP predictions. The results prove that RMOP model is capable of receiving more than 100 percent of extra data volume with respect to the classical link budget design techniques while keeping data losses under control. A specific approach usable in case of rainy events is also described.

The advent of deep space small spacecraft, as exemplified by the Mars Cubesat One (MarCO), Lunar Trailblazer, Janus, Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE), and numerous other missions, opens the possibility that a much larger number of deep space spacecraft may be launched over the next 10 years and beyond. Scientists have already acknowledged the need for distributed observation systems that are built around a fleet of well-instrumented small spacecraft.

Enabling a Larger Deep Space Mission Suite: A Deep Space Network Queuing Antenna for Demand Access

Marc Sanchez Net, Jay Wyatt, Rebecca Castano, Stephen A. Townes, T. Joseph W. Lazio, Benjamin K. Malphrus, Jeffrey A. Kruth, Chloe Hart, and Emily Mattle, *Proc. IEEE Aerospace Conference*, 2022, pp. 1–13.

In this paper, the authors investigate an integrated approach for ground stations and missions operations to enable new modes of operation while maintaining the capabilities of the current operational techniques. This integrated approach is built around three core capabilities: (1) a queuing antenna that enables monitoring the status of a much larger number of spacecraft, and allows spacecraft to transmit requests for telemetry with NASA's Deep Space Network (DSN); (2) a flexible scheduling system that expands the current DSN scheduling services to enable allocating time on DSN antennas in near real-time; and (3) a cloud-based ground data system that can be spun up and down according to how tracks are assigned by the flexible scheduling system. They show that an 18 m DSN queuing antenna equipped with cryogenic receivers would enable use of the DSN Demand Access Service for small spacecraft throughout the inner solar system, thus providing service to a large mission suite.

As the representative method in deep space navigation with high accuracy, differential one-way ranging (DOR) measurement is widely applied in deep space networks. The major challenge of DOR measurement is the invalid Quasar correction without accurate forecasting data. Generally, the reference weak Quasar TDD is estimated based on the forecasting data compensation for measurement results correction. Once the forecasting data is disturbed, inaccurate or totally unavailable, the DOR navigation loses its correction, leading to degradation of accuracy. To address the weak Quasar signal TDD estimation challenge without forecasting data support, L. Xia *et al.* propose an intelligent 2D scheme composed with correlation chart generation, two-stage auto-detection with slide-window convolutional neural network (CNN) based on ResNet-20 and iteration refinery in the following paper.

An Intelligent 2-D Chart Method with Auto-Detection for Weak Quasar Blind TDD Estimation in Deep Space DOR Measurement

Lanhua Xia, Jifei Tang, Jun Wu, Yang Chen, and Rabi Mahapatra, *IEEE Trans. Aerospace and Electronic Systems*, 2022.

The validation experiment is established with developed RS-SDR systems, which are installed in ground stations for space DOR navigation and positioning. Results show that the presented 2D correlation chart extends the system weak Quasar signal detection ability with signal SNR that can reach −23 dB. The overall accuracy of the designed two-stage auto-detection for Quasar correlation spectral line search is 85.17 percent. The proposed scheme improves the utilization rate of Quasar data collected by the system by 24.01 percent. The average P-F curve fitting residue error, which reflects the TDD estimation accuracy, is 0.1931/rad. It shows an equivalent precision to accurate forecasting data processing, which meets the DOR measurement accuracy requirements.

The IoDST is envisioned to provide reliable communication services to future deep space exploration missions. An IoDST system could comprise three networks: interplanetary backhaul, planetary inter-spacecraft network, and planetary network. An interplanetary backhaul network is characterized by extremely long and variable propagation delays and also associated with high link error rates, link outages due to orbital obscuration with the loss of line of sight, and bandwidth asymmetry in the forward and reverse channels. To maximize the TCP throughput performance and minimize delay, A. Masood *et al.* design an intelligent CC scheme called OAC-TCPCC in the following paper.

Intelligent TCP Congestion Control Scheme in Internet of Deep Space Things Communication

Arooj Masood, Taeyun Ha, Demeke Shumeye Lakew, Nhu-Ngoc Dao, Sungrae Cho, IEEE Transactions on Network Science and Engineering, 2022.

In particular, ensuring reliable communication in IoDST requires addressing challenges engendered by the unique characteristics of IoDST, including long propagation delays, link outages, high error rates, and asymmetric bandwidths. The transmission control protocol (TCP) layer functionalities thus are crucial for ensuring reliable IoDST communications. However, existing TCP congestion control (CC) protocols present poor performance in IoDST communications, due to the dependence of traditional window-based CC approaches on pre-configured rules to adjust transmission rate against the aforementioned unique characteristics. In this paper, the authors propose an intelligent CC scheme called optimistic actor-critic-based TCP congestion control (OAC-TCPCC) to solve the problems of the challenging link conditions in IoDST. OAC-TCPCC dynamically determines optimal congestion window for data transmission over IoDST communication links to maximize the TCP throughput performance and minimize file transfer time.