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A compact, light-weight high data-rate antenna system for remote-sensing orbiters and space exploration

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Abstract

Upcoming space missions utilizing hyperspectral or other high-resolution sensors will generate a vast amount of data in orbit. The average communication duration between a spacecraft in low Earth orbit (LEO) to a dedicated ground station is short and in addition, due to the high amount of data to be transferred at link times, a high-performance communication system on board of the satellite is indispensable.

A solution that provides longer acquisition times with the ground station is to employ a high data-rate inter-satellite link to a geostationary relay satellite, which requires a flat, compact, steerable, light-weight yet robust antenna. Such an antenna system (antenna module plus pointing module) was developed for S-Band at the Institute of Astronautics (Technische Universität München), in cooperation with German space companies, research institutes and the German Aerospace Center (DLR). Its successful operation via the geostationary relay satellite Artemis was demonstrated in cooperation with ESA in 2007.

This paper describes the evaluation of an antenna system in the Ka-Band, as a successor to be developed in the next two years for high data rates and the various applications of such an antenna system.

Keywords: Inter-satellite link; Ka-Band; Real-time communication

1. Introduction

One central field of research at the Lehrstuhl für Raumfahrttechnik (LRT) is the development of new technologies for robotic applications in space. An integral part of this research is done in the domain of on-orbit servicing (OOS) missions which will allow the refurbishing and/or refueling of aged spacecraft to prolong their operating time at minimum cost instead of launching a replacement satellite. A key requirement for OOS and robotics in space is the establishment of an enhanced communication link that allows real-time operations for as long as possible. The servicing spacecraft will have to perform approach maneuvers including multiple attitude changes. Consequently, the maintenance of a continuous communication link requires a steerable antenna system. Additionally, the video and sensor data, that has to be transferred during tele-commanding, requires high data rates.

Another type of spacecraft that demands higher data rates to Earth are current and upcoming Earth observation spacecraft with highly sophisticated payloads like hyperspectral sensors. Studies conducted by

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Table 1
Current and upcoming earth observation missions and their downlink data rate.

Satellite	Downlink data rate (Mbps)	Launch date
Landsat 7	150	1999
Spot 5	50	2002
Worldview 1	800	2007
Geo-Eye 1	720	2008
Rapid Eye	80	2008
EnMap	320	2012 (scheduled)

Harikrishnan [1] at the LRT revealed the rising demands of downlink capacity over the past years and one reason for this development are these scientific and other Earth observation payloads that contain sensors that generate vast amounts of data.

Table 1 shows recent and upcoming satellites and their downlink capacity. Hyperspectral sensors generate huge amounts of data in orbit that have to be transferred to ground terminals for analysis. The demand for higher resolutions for cartographic usage also led to the need of routing more bits per orbit revolution to Earth.

In this paper two variables, influencing the amount of data that can be received from a servicer satellite (which we take as our running example) or an Earth observation satellite, are analyzed. The first is the link access time (LAT), during which data transfer is possible and the second is the high data rate (HDR) that can be realized. Improving these variables is crucial for the realization of tele-operated robotic applications in space. Finally an inter-satellite link antenna system is presented that allows improvement of both parameters.

1.1. Link access time (LAT)

The link access time is the theoretical maximum time, in which a communication link is usable to transfer data. Strictly speaking this excludes the time in which the communication is built up. In this paper the term LAT is used in a wider definition and describes the total link time, and it is assumed that a communication link is possible whenever the two communicating systems share a direct line of sight.

During an OOS mission a servicer satellite will approach a target satellite to capture it and to accomplish complex OOS activities (e.g. attitude control or orbit transfer procedures). After analyzing the movement of the target satellite, the servicer satellite will approach the target and initiate docking. During this capture phase the servicer satellite will have to perform multiple attitude correction maneuvers. This will change its attitude relative to a receiver (relay satellite or ground terminal). Continuous communication links during this approach are essential to tele-command a servicer spacecraft and observe the approach at almost real-time conditions on Earth. These requirements for a continuous communication link will be applicable for any tele-commanded robotic mission (e.g. Rokviss, [2]).

Not only OOS missions are in need for longer LATs. New generations of Earth observing spacecraft are equipped with scientific payloads that generate high amounts of data. This data is usually transferred to Earth using the most common communication architecture called Store and Forward [3]. In this architecture the payload data are stored on board of the spacecraft until it can be downloaded to a ground station.

Other communication architectures, which are used for data collection missions are either broadcasting the signal to various ground stations or using a relay satellite to route the data [3]. Using several ground stations will significantly increase the cost of the mission. Since the mission data will be usually collected and prepared for the science community in one place this solution will not significantly add any value but will raise substantial cost instead.

The later solution including a data relay satellite (DRS) yields a great potential of prolonging the link access time without adding ground stations. As Stoll [4] and Raif [5] showed the rise of link access time for a LEO spacecraft using data relay communication architecture can be improved to high values of LAT depending on the exact orbit parameters of the LEO satellite. The basic elements of such a data relay communication architecture for LEO satellites is shown in Fig. 1.

As seen in this figure, this communication architecture is based on the use of a geostationary relay satellite (e.g. ARTEMIS). The relay satellite is in constant contact with the user's ground terminal and provides a feeder up- and downlink. The LEO spacecraft communicates with the relay satellite through an inter-satellite link (ISL) which allows a very long LAT because the time in which the two satellites do have a direct line of sight can be up to 60 min or more per orbit, depending on the exact orbit parameters of the LEO spacecraft.

1.2. High data rate (HDR)

Apart from the prolonged LATs an increased data rate plays a major role. First experiments with an engineering model of the compact light-weight antenna system LISA and the geostationary ESA relay satellite ARTEMIS show [4], that LISA features a data rate of