Needs for Communications and Onboard Processing in the Vision Era

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Abstract-- **The NASA New Millennium Program (NMP), in conjunction with the Earth Science Enterprise Technology Office, has examined the capability needs of future NASA Earth Science missions and defined a set of high priority technologies that offer broad benefits to future missions, which would benefit from validation in space before their use in a science mission. In the area of spacecraft communications, the need for high and ultra-high data rates is driving development of communications technologies. This paper describes the current vision and roadmaps of the NMP for the technology needed to support ultra-high data rates downlink to Earth. Hyperspectral land imaging, radar imaging and multi-instrument platforms represent the most demanding classes of instruments in which large data flows place limitations upon the performance of the instrument and systems. The existing and prospective Data Distribution (DD) modes employ various types of links, such as DD from low-earth-orbit (LEO) spacecraft direct to the ground, DD from geosynchronous (GEO) spacecraft, LEO to GEO relays, multi-spacecraft links, and sensor webs. Depending on the type of link, the current data rate requirements vary from 2 Mbps (LEO to GEO relay) to 150 Mbps (DD from LEO spacecraft). It is expected that in the 20-year timeframe, the link data rates may increase to 100 Gbps. To ensure such capabilities, the aggressive development of communication technologies in the optical frequency region is necessary. Current Technology Readiness Levels (TRL) of the technology components for space segment of communications hardware vary from 3 (proof of concept) to 5 (validation in relevant environment).**

Development of onboard processing represents another area driven by increasing data rates of spaceborne experiments. The technologies that need further development include data compression, event recognition and response, as well as specific hyperspectral and radar data processing. Aspects of onboard processing technologies requiring flight validation include: fault-tolerant computing and processor stability, autonomous event detection and response, situation-based data compression and processing. The required technology validation missions can be divided in two categories: hardware-related missions and software–related missions. Objectives of the first kind of missions include radiation-tolerant processors and radiation-tolerant package switching communications node/network interface. Objectives of the second kind of missions include autonomous spacecraft operations and payload (instrument-specific) system operations.

I. INTRODUCTION

NASA's imaging strategy for the 21st century calls for supporting the needs of the Earth Observation System (EOS) missions with a suite of smaller and more capable satellites. These satellites will carry advanced hyperspectral imaging instruments and synthetic aperture radar that will generate terabits of data to meets the scientists' demand for higher spectral and spatial resolutions. Transmitting these data to Earth and distributing them to the science investigators will require substantial advancement of many currently existing technologies.

In this paper, the future science requirements are discussed in Section II, where instrument data rates for future high spectral and spatial resolution imaging instruments data rates are projected for both the years of 2010 and 2020. Section III describes future communications technology capabilities required to accommodate the science requirements. These communications technologies include X-Band, Ka-Band, and optical frequencies and assessment of the current state-of-the-art, and future communication capabilities in the years 2010, 2015 and 2020. In Section IV, on-board processing technology capabilities are discussed where the need for autonomy, fault tolerant and radiation-tolerant software and hardware are required. Section V presents conclusions and recommendations for future communications and on-board processing technologies.

II. SCIENCE REQUIREMENTS

Improved monitoring and management of Earth's resources and environment requires the deployment of high spatial and spectral resolution instruments on board of the spacecraft. The spatial and spectral resolution obtained with the advanced spaceborne hyperspectral imagers, Synthetic Aperture Radars (SAR) provides information on Earth's dynamic processes. SARs provide valuable information on ocean dynamics, wave and surface wind speed and direction, desertification, deforestation, volcanism, and tectonic activities. Also, hyperspectral imagers generate high spectral resolution images of surface features, such as soil and vegetation that enables geologists, agriculturalists and others to identify mineral deposits and to monitor crop health. Both Instruments generate Gbps and the challenge is be able to deliver this information as soon as possible to the principal investigators. Table 1 shows the future trends of the high data rate for the missions around the Earth. The table clearly shows that the near future is going to demand an ultra high rate transmission from the satellite to the ground station. This need must be addressed in the very near future.

TABLE I
Instrument Data Rates and downlink rates for each option

Instrument/Year	2010	2020
Hyperspectral	10 Gbps	100 Gbps
SAR	10 Gbps	60 Gbps
LIDAR	150 Mbps	1 Gbps
Downlink Data Rate to Earth	> 1 Gbps	> 10 Gbps

In addition to the predicted data rates above the scientific community has defined the peak data rates needs for several types of links. These peak rates are shown in Table II. The types of links are classified as a) DD from LEO Earth Orbiting spacecraft to ground, b) DD from GEO to ground, c) Leo to Geo, d) Multi-spacecraft links, e) sensor web. These types of links are shown in Fig 1.

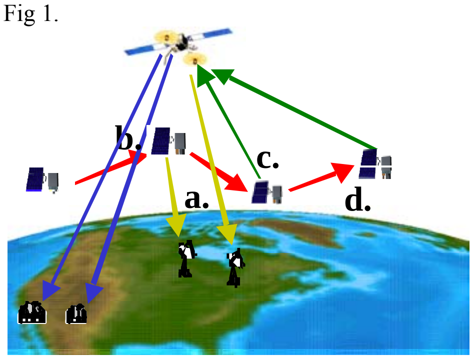

Fig 1. Types of links

III. FUTURE COMMUNICATIONS TECHNOLOGY CAPABILITIES

In order to accommodate science needs and be able to deliver the desired data rate several communications technologies and their associated components have to be developed in the near future. Using the several types of links defined above, these technologies and their technology readiness levels (TRL) are listed below in Table III.

TABLE II
Data Rate Peak Needs for each type of link

Type of Link	State-of-the-art	2010	2015	2020
A	X-Band, 150Mbps	10 Gbps	25 Gbps	100 Gbps
B	150 Mbps	10 Gbps	25 Gbps	100 Gbps
C	2 Mbps	150 Mbps to 1 Gbps	-	-
d	4 Mbps	45 Mbps	155 Mbps	-
e	100 bps	a, b, c, d	a, b, c, d	a, b, c, d

TABLE III
Major Communications Technology Components and their Current TRL

Type of Link	State-of-the-art	Future Technology Capability	Technology for Space	TRL
a	X-Band	Ka-Band and Optical	•Phased Array Antennas •Acq/Trk for Optical •High power/BW Lasers	3-5
b	Ku- and X-Band	Ka-Band and Optical	•Large Deployable Antennas •Acq/Trk for Optical •High power/BW Lasers	3-5
c	S- and Ku-Band	Ka-Band and Optical	•Agile Reconfig Antennas •Low Noise Receivers •High Energy Transmitter •Acq/Trk for Optical •High power/BW Lasers	3-5
d	UHF	UHF to W-Band and Optical	•Multi-Beam Antennas •Acq/Trk for Optical •High power/BW Lasers •Miniature Circuit Component	3-5
e	None	All of the above	All of the above	

IV. FUTURE ON-BOARD PROCESSING TECHNOLOGY CAPABILITIES

Recent advances in science instruments technology continues to widen the gap between the volume of data collected by the instruments and the capacity of the data link to Earth. Moreover, the rate at which scientists analyze data is significantly less than the rate of data acquisition. To close or reduce these gaps, scientifically important information content of the downlink data should be maximized. Thus the development of new technologies to intelligently extract and process science data represents another challenge driven by increasing data volumes and rates of spaceborne experiments. These technologies that need further development can be classified in two classes, those requiring validation in space and those that don't. Here in this paper we will consider these technologies whether or not they require validation in space, such as data compression, data reduction, reconfigurable-processors, high-speed data bus etc. Several aspects of onboard processing technologies especially those requiring flight validation include several major topics, such as: Autonomy, Which include: Setting mission priorities, science event handling, on-board resource management, Autonomous formation keeping, on-board data management, feature detection, recognition and response, and science decision making processes. In addition fault-tolerant computing and processor stability, situation-based data compression and processing. The required on-board technology validation missions include software-related and hardware-related missions. Software-related missions face several challenges such as mission planning, and science data extraction for interesting targets. Objectives of the software-related mission include on-board planning, synchronization, hazard checking, resource management and event handling. Science objectives include target handoff, region classification, template matching, and model-based identification. . On the other hand most of hardware-related missions focus on radiation-tolerant processors and communications node (package switching) / radiation tolerant network interface. Reliability and stability of radiation-tolerant processors and its ability to withstand >100Krad is the current challenge for this technology. For the communication node in the sky, technology challenges such as: radiation-tolerant network interfaces, common data exchange architecture, and distributed systems have to be resolved.

V. CONCLISIONS AND SUMMARY

The demand to improve monitoring of the Earth's resources and its dynamic processes drives scientists to require high spatial and spectral resolution from Earth-orbiting satellites. The instruments needed to support this demand are hyperspectral imagers, synthetic aperture radars, and lidars. In viewing the projected demands in 2010 and 2020, we find that the hyperspectral and SAR imagers' demand for higher resolution drives the instrument data rates from 10 Gbps in 2010 to 100 Gbps in 2020. Future communications technology capabilities must include Ka-Band and Optical, besides the current X-Band communications. The need for autonomy and radiation-tolerant processors are identified as key components for the future on-board processing technology capabilities.

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REFRENCES

[1] W. Schober, F. Lansing, K. Wilson, and E. Webb, "High Data Rate Instruments Study," Jet Propulsion Laboratory publication 99-4.

[2] F. Lansing, K. Bhasin, and G. Prescott, "Ultra-High Data Rate Communications," Earth Science Enterprise Technology Workshop, January 24, 2001.

[3] G. Bothwell, L. Lemmerman, A. Walton, "On-Board Processing," Earth Science Enterprise Technology Workshop, January 24, 2001.