Link Analysis of High Throughput Spacecraft Communication Systems for Future Science Missions

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***Abstract*— NASA's plan to launch several spacecrafts into low Earth Orbit (LEO) to support science missions in the next ten years and beyond requires down link throughput on the order of several terabits per day. The ability to handle such a large volume of data far exceeds the capabilities of current systems. This paper proposes two solutions, first, a high data rate link between the LEO spacecraft and ground via relay satellites in geostationary orbit (GEO). Second, a high data rate direct to ground link from LEO. Next, the paper presents results from computer simulations carried out for both types of links taking into consideration spacecraft transmitter frequency, EIRP, and waveform; elevation angle dependent path loss through Earth's atmosphere, and ground station receiver G/T.**

I. Introduction

In the next tens years NASA plans to launch into low Earth orbit (LEO) several spacecrafts with radio science instruments onboard for remote sensing of the Earth. These instruments will acquire several hundred gigabits of data per orbit. A few representative examples of future ultra-high data science missions and their proposed launch dates are the NASA-ISRO Synthetic Aperture Radar (NISAR) (2020), Surface Water and Ocean Topography (SWOT) (2019), and Hyperspectral Infrared Imager (HyspIRI) (2022). The ability to handle such a large volume of science data per orbit far exceeds the capabilities of NASA's current space and ground assets [1]-[3].

This paper proposes two solutions: first, a high data rate link between the LEO spacecraft and ground via relay satellites in geostationary orbit (GEO). Second, a high data rate direct to ground link from LEO. Next, the paper presents results from computer simulations carried out for both types of links taking into consideration spacecraft transmitter frequency, EIRP, and waveform; elevation angle dependent path loss through Earth's atmosphere, and ground station receiver G/T.

II. Ka-Band Space-to-Space LEO-to-GEO Link

The relay satellites are assumed to be in geostationary orbit (GEO). Notional communication links between LEO and GEO are schematically illustrated in Fig. 1. The LEO-to-GEO link is designated as the return link (RL) to the relay satellite and operates at Ka-band (25.5-27.0 GHz) frequencies. The GEO-to-LEO forward link (FL) is relatively a low data rate link and primarily used for commanding, hence excluded form discussions in this section.

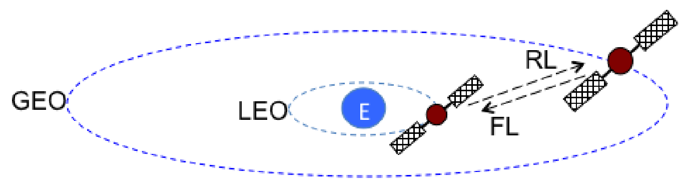

Fig. 1. LEO-to-GEO relay satellite communication link.

The simulated relay satellite G/T as a function of the LEO spacecraft EIRP, for fixed link data rates, is presented in Fig. 2. The results indicate that for a fixed link data rate, as the relay spacecraft G/T increases the required LEO spacecraft EIRP decreases. The decrease in EIRP is an advantage, since it implies a smaller transmit antenna on LEO spacecraft.

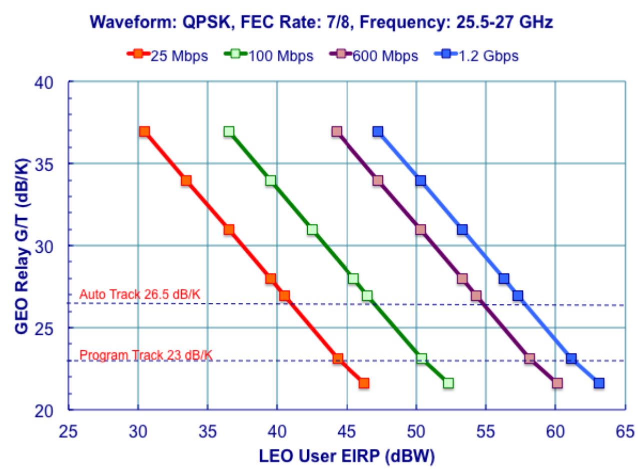

Fig. 2. Relay satellite G/T vs. LEO spacecraft EIRP.

III. V-Band GEO-to-GEO Intersatellite Links

Notional GEO-to-GEO intersatellite links are schematically illustrated in Fig. 3. The forward (FL) and return (RL) links operate at V-band frequencies (59-64 GHz), but with opposite sense of polarization to minimize interference. In carrying out the simulations, the assumptions made are that the output power (P_{out}) from the traveling-wave tube amplifier (TWTA) onboard the relay satellite is 70 watts and the relay satellite transmit and receiver antenna diameters are identical. The simulated relay satellite EIRP as a function of the antenna diameter at V-band is presented in Fig. 4. The results indicate as expected that the EIRP increase as the antenna diameter increases. The simulated intersatellite link data rate as a function of the relay satellite EIRP is presented in Fig. 5. The results indicate that the bandwidth required for 3 Gbps data rate using 8PSK rate 9/10 waveform is about 1.5 GHz. If a higher spectrally efficient 32APSK rate 9/10 waveform is selected, then the bandwidth reduces to 0.9 GHz.

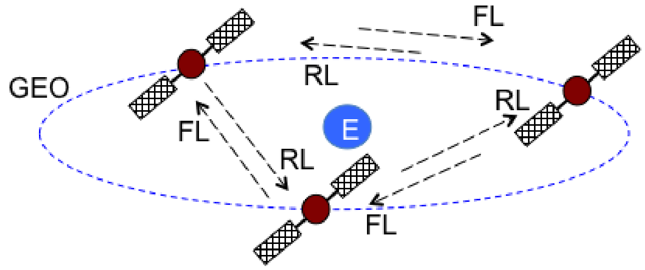

Fig. 3. GEO-to-GEO intersatellite links.

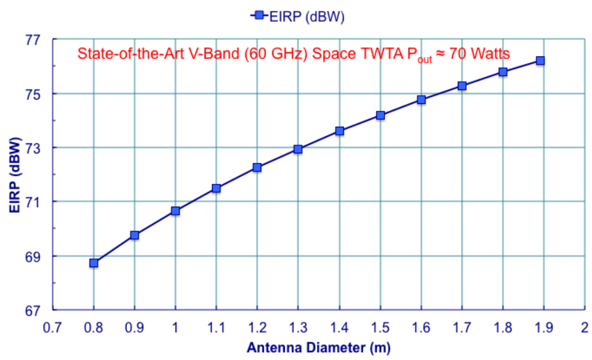

Fig. 4. Relay satellite EIRP vs. antenna diameter.

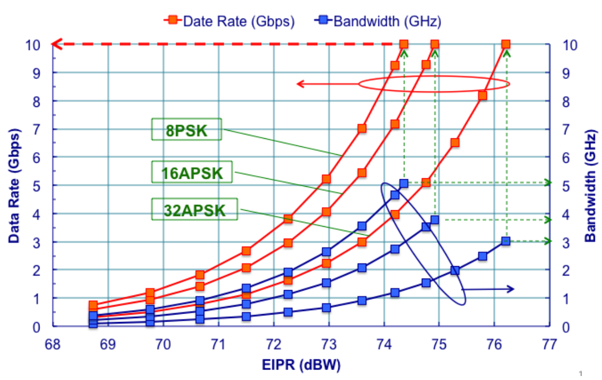

Fig. 5. Data rate and bandwidth vs. relay satellite EIRP.

IV. K-Band GEO-to-Ground Link

Computer simulations are carried out for a relay satellite to ground station down link at K-band frequencies (20.2-21.2 GHz). The saturated output power (P_{sat}) of the TWTA onboard the relay satellite is assumed to be 160 watts and is backed off (OBO) by 5.3 dB to enable transmission of a 32-APSK LDPC Rate 9/10, waveform. The simulated relay satellite EIRP as a function of the ground receiver G/T is presented in Fig. 6. The results indicate that for a link data rate of 3 Gbps, the relay satellite and ground station antenna diameters can both be equal to 3m. If the relay satellite antenna diameter is reduced to 0.5 m then, the ground station requires 18 m diameter antenna to close the link.

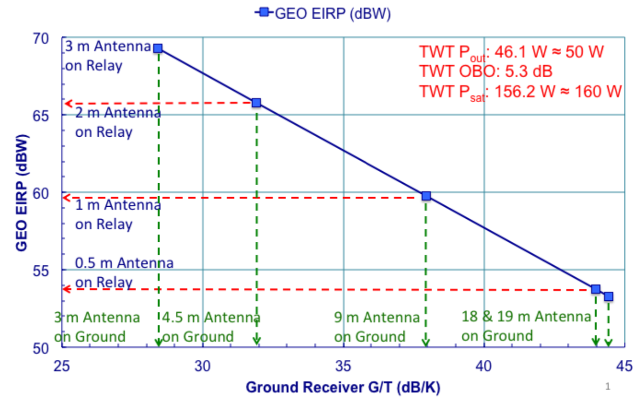

Fig. 6. Relay satellite EIRP vs. ground receiver G/T.

V. Ka-Band LEO-to-Ground Link

Computer simulations are carried out for a direct down link from LEO spacecraft to a ground station at Ka-band frequencies (25.5-27.0 GHz). The simulated data rate as a function of the LEO spacecraft EIRP is presented in Fig. 7. The results indicate that for a down link data rate of 1.2 Gbps with 8PSK rate 9/10 waveform, the bandwidth required is 0.6 GHz.

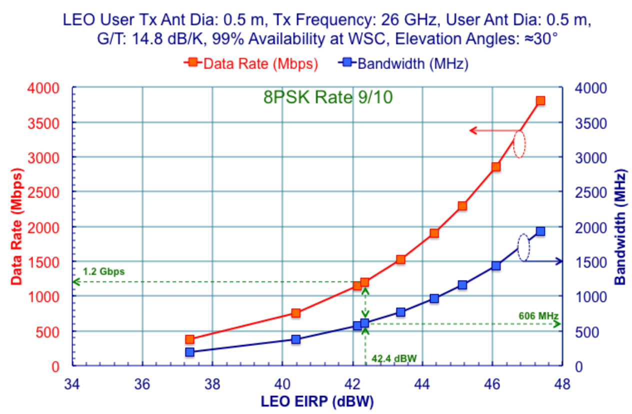

Fig. 7. Data rate and bandwidth vs. LEO spacecraft EIRP.

VI. Conclusions

Results from computer simulations carried out for high data rate LEO-to-GEO, GEO-to-GEO, GEO-to-ground, and LEO-to-ground links to down load large volume of science data are presented.

References

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