International Journal of Pure and Applied Mathematics
Volume 118 No. 16 2018, 1227-1244
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

Study of Data Relay Satellite System and its Relevance to Indian context

Gottimukula PraveenReddy[1], Imteyaz Ahmad[2], Killedar Pankaj Damodar[3], Anjaneyulu K V V S S S R[4]
[1 2 3]ISRO Satellite Centre, Bangalore, India
gpraveen@isac.gov.in
[4]ISRO Telemetry Tracking & Command Network (ISTRAC),
Bangalore, India

January 1, 2018

Abstract

Objectives: Availability of reliable, affordable and continuous communication link is one of the fundamental requirements for any space mission, as it forms the umbilical cord connecting the spacecraft to ground control and commanding networks. The quality and continuity of the link directly influences the payload data turn-around time for effective payload utilization of Low Earth Orbit (LEO) missions/ remote sensing missions. Also, for crucial missions such as Human Space Programme (HSP) and Inter Planetary exploration, it becomes imperative to have a robust communication link between ground and space segment.

Methods/Statistical analysis: Data Relay Satellite System (DRSS) presents a simple solution by seamlessly providing a stable link between Remote Sensing Satellites constellation in-orbit and its users on the ground. A data relay satellite placed either in Geo-synchronous orbit or Molniya orbit serves as communication/data link to Low Earth Orbit (LEO) manned/ unmanned missions. It provides a near continuous visibility of LEO spacecraft. Conventional ground stations can have visibility of LEO missions in discontinuous fragments (for a maximum of ∼20 minutes) with four to five orbital visibilities over a day. Even with about 40 stations located geographically over different sites on the globe, only about two third coverage of the orbit can be achieved. Since most of the earths surface is covered by water, a majority of ground stations have to be located on ships resulting in exorbitant costs of the ground network.

Findings: Single satellite based DRSS improves visibility of a LEO spacecraft to approximately half an orbit. Two such relay satellites of DRSS can provide near continuous coverage. Effectively, remote sensing missions utilization is increased multi-fold by availability of payload data. Also better Telemetry Tracking & Command (TT&C) coverage achieved for the LEO satellite. Similar network concept exists internationally by other space agencies. Such a system will also be effective for manned missions where near continuous contact with the crew module is of prime importance and for launch vehicle trajectory tracking. This apart even for GEO stationary spacecrafts TTC functions can be easily met during transfer orbit operations by DRSS, thereby avoiding the need of using international ground network.

This Paper discusses the configuration of Data Relay Satellites Systems and related Case Studies in the Indian context.

Key Words : Data Relay Satellite; Spacecraft; Communication; Indian Data Relay Satellite System (IDRSS)

1 Introduction

Data Relay Satellite System (DRSS) is primarily meant for providing continuous/real time communication of Low-Earth-Orbit (LEO) satellites/human space mission to the ground station. A data relay satellite in the Geo-stationary Orbit (GEO) can see a low altitude spacecraft for approximately half an orbit. Two such relay satellites, spaced 180^o apart in GEO, could theoretically provide continuous contact for any spacecraft in LEO.

The data rates of Earth Observation (EO) satellites are steadily increasing and will exceed 1 Gbps in near future with high resolution multispectral & hyper spectral imaging systems and memory sizes of onboard designed for beyond 10s of Terra bytes. Thus, data transfer from earth observing LEO satellite to Ground Station (GS) is becoming a real challenge because of the limited visibility of the LEO spacecraft from GS, allowing only short time for data download. Further, continuous visibility is an indispensable requirement for manned missions as human lives are involved. Study shows that nearly 41 ground stations provide about 70% visibility of low earth missions. The above challenges can be met through the use of relay satellites especially in Geostationary Orbit wherein, EO satellites orbiting in LEO transmit data to GEO satellite which then relays the data to ground as it is always visible to the ground station.

In the global scenario, evolution of Tracking and Data Relay Satellite System (TDRSS) had happened to support communications and tracking services for NASAs LEO spacecrafts which was earlier carried out primarily by global network of ground stations. As, this network provided only limited coverage (¡20% of an orbit) NASA began development of the TDRSS[1][4] in the 1970s, as a means of providing cost-effective near global coverage to manned and unmanned low-earth-orbiting spacecraft.

The European Data Relay System(EDRS)[2][3] is designed to transmit data between low-orbiting satellites and the EDRS payloads in geostationary orbit using innovative laser communication technology and send them down to Earth, forming the Space Data Highway. Consisting of a hosted payload (EDRS-A) on a commercial telecom satellite and a dedicated satellite (EDRS-C) in geostationary orbit. Similarly Japan launched its own Data Relay and Tracking satellite (DRTS) named Kodama in 2002; Also China has Chinese Data Tracking and Relay System (CTDRS) with 3 satellites operational.

2 Need aspects of Data Relay Satellite for India

India has one of the largest constellations of remote sensing satellites in operation in the world today. An Indian Remote Sensing (IRS) satellites system which was commissioned with the launch of IRS-1A in 1988 provides data in a range of spectral bands, spatial resolutions and swath. The data is used for several applications covering agriculture, water resources, urban development, mineral prospecting, environment, forestry, drought and flood forecasting, ocean resources etc.,

ISRO is also planning for Human Space Programme (HSP) which needs availability of continuous and reliable link with crew module. Also, ISRO has its own family of launchers namely PSLV, GSLV-Mark II, and GSLV-Mark III which is under development and likely to be commissioned shortly. As required, international TTC networks are hired for tracking the launch vehicle.DRS will cater to TTC requirements of HSP and launch vehicle tracking. Typically most of launchers inject the geostationary satellite in GTO. Orbit raising maneuvers for Geosynchronous Transfer Orbit (GTO) to GSO is carried out by spacecraft propulsion. DRS spacecraft will cater to the TTC requirement of spacecraft in Low Earth Orbit Operations (LEOP) and transfer orbit.

Few of the prime advantages are summarized below:

- **Near-real-time Controllability of satellite**

  DRSS program will initiate a GEO based data relay infrastructure to provide space-space-ground and ground-space-space communication. Communicating with satellites in all orbits and for longer duration in each orbit increases the flexibility and reactivity in spacecraft operations. This will also improve the Telemetry Tracking and Commanding (TTC) functions for manned missions and LEO missions.

- **On-board Payload Data Accessibility**

  DRSS provides payload data services in real time thus reducing the delivery time of data from several hours to just a few minutes. The DRSS enables contact for almost the entire orbit time - giving user access to spacecraft data almost instantly and over previously unreachable areas. It relieves design constraints on spacecraft systems like data handling systems and thus increasing the capacity for extra payload.

- **Increase of in-orbit data through-put**

  The state-of-the-art laser/optical communication technologies facilitate data transmission at upto Gigabits/second. Combining the high-speed data transfer and the increased contact time results in a data transmission capacity of tera-bits/day shared among DRSS users.

- **Optimized ground infrastructure and operations**

  DRSS simplifies end-to-end LEO operations. Routing the data through the DRSS infrastructure directly to processing facilities reduces the need for an extensive ground station network.

- **Data security**

  It also avoids sovereignty issues connected with routing the required data through foreign territory or infrastructure. The high availability and redundancy of the DRSS as well as the future system extensions provide a safe and full-proof data transmission infrastructure.

3 Visibility of LEO Satellites and HSP using Data Relay Satellite

The visibility of LEO satellite depends on LEO satellite altitude and the orientation of the orbital plane. This determines the visibility of LEO satellites from geostationary orbit and thus the LEO-GEO contact time to fulfill downlink capacity. The selection of optimum orbital positions for DRS satellites is subjected to coverage of LEO users, feeder link availability for data transfer to & fro from ground.

For the study purpose, HSP and LEO satellites considered are in the following orbits

- HSP orbit($\sim$250 km)
- 400 km sun synchronous orbit
- 500 km sun synchronous orbit

Assuming a minimum elevation of 10 deg with respect to ground stations for a GEO Synchronous Orbit (GSO) satellite, the maximum separation possible across two GSO satellites was worked out. It was found that with 1400 separation between the two GSO satellites will provide visibility of both spacecraft at a ground station located in India with around 10 degrees elevation. Also 140 degree separation provides nearly continuous visibility for HSP and LEO missions (94% for HSP, 97.8% for 400 km sun synchronous orbit, 98% for 500 km orbit). Figure 1 shows the service area of GEO satellite to HSP flight and LEO satellites. Figure 2 shows the Coverage area of DRS satellites with 140 deg separation and 10 deg elevation contour.

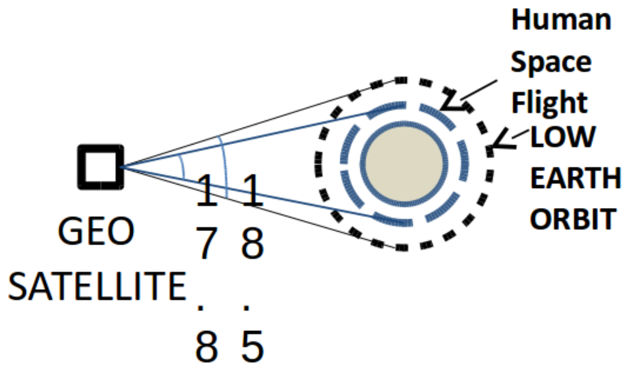

Figure 1: Service area of GEO satellite to HSP flight and LEO satellites

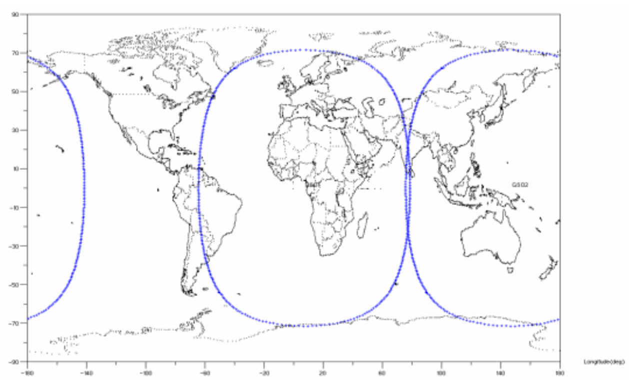

Figure 2: Coverage area of DRS satellites with 1400 separation and 100 elevation contour

4 Architecture of a Generic DRSS satellite

DRSS architecture is categorized into three segments, namely Space Segment, Ground Segment and User Segment.

a) **DRSS Space Segment**

The DRSS space segment primarily consists of high altitude satellite system of GEO or Molniya class, defined in a modular way providing several payloads satisfying the data relay service requirements at different orbital positions with on-board state-of-the-art technologies.

b) **DRSS Ground Segment**

The Ground Segment consists of mission and satellite control centre, which includes the TTC, satellite control and mission control elements. Its task would be to control and operate the DRSS GEO Space Segment. DRSS Network Control Centre, whose task will include managing and operating the end to end data relay links and to provide data relay customer interface for mission request, mission planning, scheduling and mission execution.

c) **DRSS Space Segment**

The DRSS space segment primarily consists of high altitude satellite system of GEO or Molniya class, defined in a modular way providing several payloads satisfying the data relay service requirements at different orbital positions with on-board state-of-the-art technologies.

d) **DRSS Ground Segment**

The Ground Segment consists of mission and satellite control centre, which includes the TTC, satellite control and mission control elements. Its task would be to control and operate the DRSS GEO Space Segment. DRSS Network Control Centre, whose task will include managing and operating the end to end data relay links and to provide data relay customer interface for mission request, mission planning, scheduling and mission execution.

e) **DRSS User Segment**

The users of DRSS services can be broadly categorized as Institutional users (e.g. Space agency), Commercial users (e.g. Other Launcher/Satellite Agencies) and Human Space Missions.

Figure 3 shows the Generic Data Relay Satellite System Architecture with all the segments of DRSS.

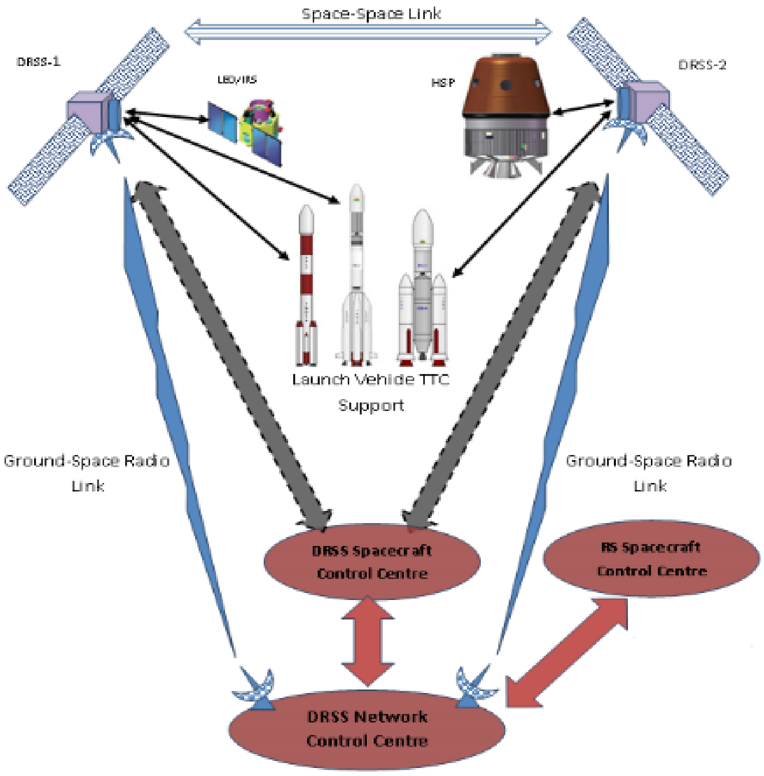

Figure 3: Generic Data Relay Satellite System Architecture

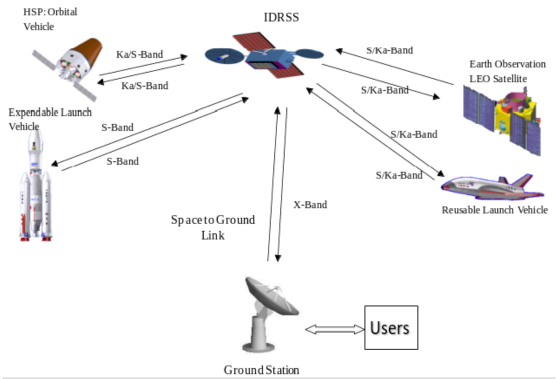

Figure 4: Indian Data Relay Satellite System Architecture

5 Proposed Indian DRSS Configuration

Indian Data Relay Satellite System (IDRSS) configuration is conceived as a system capable of providing Tracking and Data Acquisition (T&DA) support for all types of low altitude spacecraft, both manned and unmanned. Three frequency bands are considered; Inter Orbit Link (IOL) which uses Ka-band and optical frequencies for high data rate users (up to several hundreds of Mbps) and S-band for low return data rate users (few Mbps)[5]. User communication requirements are defined in terms of data rates and the coverage required.

IDRSS service requirements

- High Data Rate Imaging data transmission of LEO satellites.
- Low Data Rate Tele-command, Telemetry and Tracking operations of LEO satellites.
- Medium Data Rate mission data and tracking for Human Space Flight Mission.
- Low data rate for launch vehicles tracking operations.
- Low data rate for TTC functions during Transfer Orbit (T.O.) operations for GEO spacecraft.

IDRSS data rate specifications and service requirements are given in Table 2 and Table 3 respectively.

Table 1: Coverage for HSP and LEO Satellite of different altitudes with data relay satellite

Number of GSO Satellites	**HSP (250Km)**	**LEO spacecraft in 400 Km**	**LEO spacecraft in 500 Km**
Single GSO	52%	65.7%	67.7%
Two GSOs, (120 deg separated)	88.4%	93%	94.2%
Two GSOs, (140 deg separated)	94%	97.8%	98%
Two GSOs (160 deg separated)	99.4%	100%	100%
Two GSOs, (171 deg separated)	100%	100%	100%

Table 2: Data Rate Specifications for IDRSS Communication link

User Service	**Forward Data Rate**	**Return Data Rate**	**Type of Access**	**Band**	**Applications**
Low Data Rate	10 Kbps	10 Kbps	Multiple	S	IRS Class TM/TC
Medium Data Rate	100 Kbps	2 Mbps	Single	S	Manned Mission, Rocket TM, Scientific Missions
High Data Rate	N/A	500 Mbps	Single	Ku or Ka	IRS payload data

Table 3: Different IDRSS Services

User	Type of Service	Data Rate	Band
HSP	Forward Service (Command Uplink, Audio/Video Uplink)	24 Kbps	S
HSP	Return Services (Telemetry, Audio)	24 Kbps	S
HSP	Return Services (Data, Video)	400 Kbps	S
IRS	Forward Service (Command Uplink)	4 Kbps	S
IRS	Return Services (Telemetry Downlink)	16 Kbps	S
IRS	Return Services (Payload Data)	320/480 Mbps	Ka
LV	Return Services (Telemetry, Video)	24 Kbps	S
	Inter Satellite Communication	1 Gbps	Optical

- Forward Link is the link from ground control centre to the user spacecraft/vehicle via IDRSS satellite.
- Return Link is the link from user spacecraft/vehicle to user Control Centre via IDRSS satellite.
- Multiple accesses are capability of IDRSS to handle multiple, Telemetry and Telecommand carriers from/to LEO/MEO satellites.
- Single access provides both forward and return links for Medium data rates and return link for high data rates.

5.1 Options studied for IDRSS Satellites constellation

In the first option, two IDRSS satellites are placed in such a way that they are continuously visible to ground Station located at Indian mainland. These satellites will communicate with user spacecraft/Launch vehicle/HSP programme and transfer the data to the ground station. This option doesnt need inter satellite communication between the two IDRSS satellites as they are continuously visible to ground station to transfer the data. This option is depicted in Figure 5.

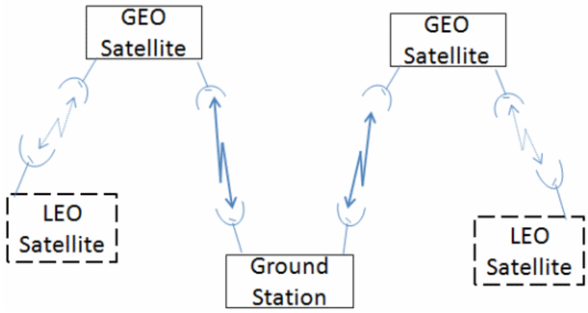

Figure 5: Two IDRSS satellites visible w.r.t ground station located in India

An alternate approach is with one IDRSS Satellite which is continuously visible to ground station located at Indian main land. This satellite will communicate with the other IDRSS satellite which is not visible to ground station using inter satellite link to transfer the data to the ground station. This approach is depicted in Figure 6.

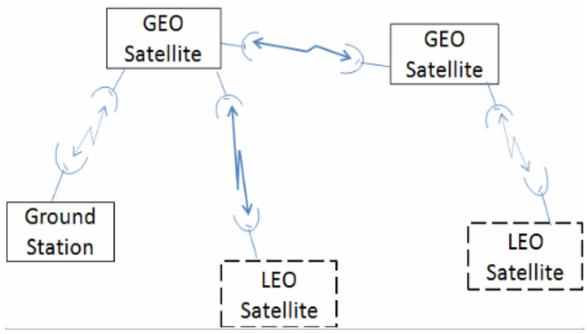

Figure 6: One IDRSS satellites visible w.r.t ground station located in India

5.2 IDRSS Spacecraft Configuration

ISRO has standardised its Satellite platform viz. I-1K, I-2K, I-3K bus. IDRSS spacecraft can be built around ISROs standard I-3K cuboid bus structure of size 2000 mm x 1770 mm x 3100 mm which has lift of mass capability of around 3.5 ton and power generation capability of around 6 kW. The electrical power system for satellite is conceived as direct energy transfer system with state-of-art Advanced Triple Junction/ Ultra Triple Junction solar cells for sunlit and Li-ion battery for eclipse operations. Attitude and orbital control system uses the body stabilized momentum biased system with momentum/transverse momentum wheels to provide a stable platform to satisfy the communication payload requirements. Thermal control system which is required to maintain within design temperature ranges shall comprise of active elements and passive elements. Propulsion system which is used for orbit raising and station keeping consists of Bi-propellant system with Mixed Oxides of Nitrogen & Mono-Methyl Hydrazine. Optical Communication Terminal (OCT) which is used for inter satellite communication has mass and power requirement around 45 kg and 125 W respectively. Total payload mass and power requirement is estimated to be approximately 350 kg and 1400 W. Payload consists of Ka/S band single access unfurlable antenna, S band phased array antenna, X band fixed reflector for feeder link, Optical telescope and OCT. Figure 7 shows deployed configuration of IDRSS spacecraft[6].

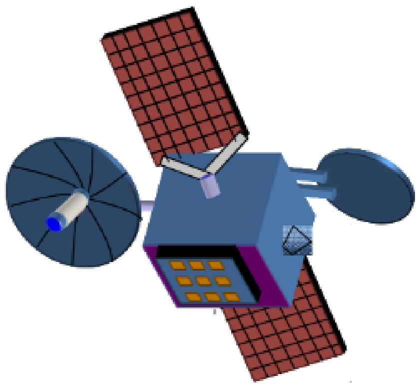

Figure 7: A typical view of IDRSS Spacecraft

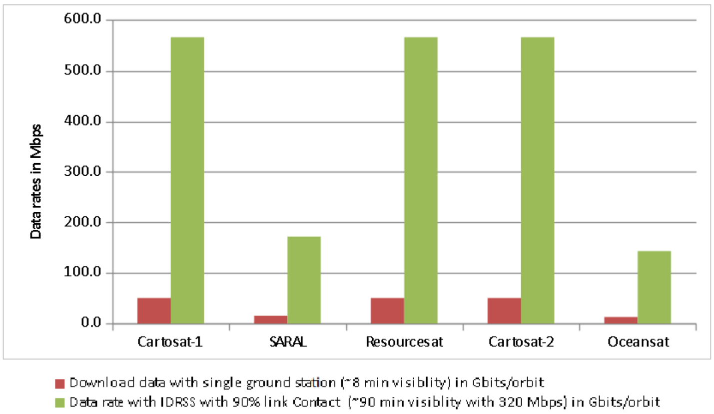

Figure 8: Chart showing increase in data throughput with IDRSS Configuration

5.3 Case Studies

5.3.1 Increase in throughput of LEO satellites

Study was carried out to estimate the increase in throughput of the data of Indian LEO satellites if IDRSS is used as a medium for data transfer from LEO to ground station in replacement with the existing mechanism where data is transferred when visibility exists between LEO satellite and ground station. IDRSS shall provide a data rate of 320/480 Mbps on each LEO-GEO inter-satellite link. This is based on the analysis of the LEO-GEO contact time, link budget analysis. Data rate of the typical IRS class of satellite with the ground station is in Mbps. The visibility of the satellite to the ground station is around approximately 5 min for a single pass over the ground station. Data that can be transferred from IRS satellite to ground station during this visibility period is in few hundreds of Gbits. If we use the IDRSS satellite configuration for Cartosat type of mission, the throughput of the payload data can be increased by a factor of ∼11 times taking into account of 90% visibility period and by a factor of ∼12 times considering 100% visibility for a single orbit.

Table 4 shows the quantum of downlink data volume available through IDRSS per orbit compared to current download volumes with single ground station of IRS class of satellites are exceeded with margin in the required downlink capacity.

Table 4: Maximum downlink data volumes per orbit for direct ground links and via Geostationary data relay

Satellites in LEO-Orbit	**Data rate to single ground station Mbps**	**Single Ground station ($\sim$ 8min Contact) Gbits/Orbit**	**Data download with IDRSS with 90% Contact ($\sim$90 min visiblity,with 320 Mbps) in Gbits/Orbit**
Cartosat-1	105	50.4	567.0
SARAL	32	15.3	172.1
Resourcesat	105	50.4	567.0
Cartosat-2	105	50.4	567.0
Oceansat	21	12.8	143.4

5.3.2 Transfer orbit Scenario for GEO Mission

For the GEO satellites launched by ISRO launchers or international launchers, the external ground station network along with Master Control Facility (MCF), Hassan, India are selected to provide continuous visibility during LEOP phases of mission. The external network is so chosen to provide dual station visibility as redundant support to Hassan for critical operations during transfer orbit. The network stations considered for this purpose are typically located at Biak, Fillmore (USA), Fucino (Italy) etc., (which belong to INTELSAT/ INMARSAT).

A typical transfer orbit visibility chart of a spacecraft is shown in Figure 9. Adequate dual station visibility, for Hassan and one other station around apogees is required.

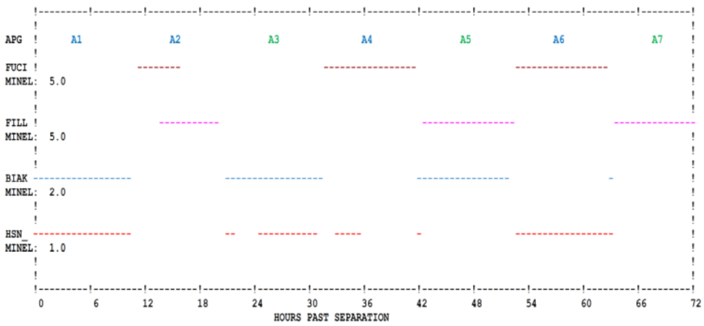

Figure 9: Transfer Orbit visibility Chart of a typical GEO satellite

By using the IDRSS, continuous visibility during LEOP phases of mission can be provided which can eliminate the need of using other ground station networks. This will result in cost advantage for the satellite operations during transfer orbit phase.

6 Conclusion

In view of increasing number of LEO satellites and launches apart from the ambitious HSP programme, it is essential to have its own DRSS for India. It not only provides self reliance in services but also increases the throughput of payload drastically. This paper describes in detail with the need of Data Relay Satellite System for India. Study has been carried out to realize DRSS on standard I-3K platform of ISRO. Various options have been proposed for IDRSS configuration. Also, case studies have been carried out on increase in throughput using IDRSS. In addition, this system will cater to the TTC function of the LEO spacecraft as well as GEO spacecraft during the transfer orbit phases. All the studies re-affirm the need and significance of having Indian Data Relay Satellite System.

References

[1] *NASAs Advanced Tracking and Data Relay Satellite System for the Years 2000 and beyond*, Daniel L. Brandel, Proceedings of the IEEE, vol. 78, Issue No. 7, July 1990

16

[2] *The European Data Relay System: Present Concept and Future Evolution*, Glullano Berretta, Proceedings of the IEEE, vol. 78, Issue No. 7, July 1990

[3] *Future Perspectives for the New European Data Relay System*, Aerospace Conference, 2008 IEEE

[4] *New TDRSS communications options for small satellites*, David J.Zillig,Kenneth L.Perko, and Kathryn G. Nelson

[5] *Geostationary data relay satellites for earth observation: the GERELEO concept*, A. Donner, H. Bischl, L. Greda, Z. Katona; DLR Institut fr Kommunikation und Navigation

[6] *Design Concepts for a Small Space-Based GEO Relay Satellite for Missions between Low Earth and Near Earth Orbits*, Kul Bhasin, Joseph Warner, Steven Oleson, James Schier, Spaceops International Conference 2014