Inter-Satellite Data Relay System (IDRS) for LEO Satellites Using a Commercially Available GEO Satellite System

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ABSTRACT

The vast majority of commercial LEO satellite missions are supported by networks of a small number of ground earth stations distributed around the globe. Due to the limited number of earth stations and the speed of the LEO satellites, these ground earth stations can only provide intermittent communications services. To date a typical LEO satellite is supported by typically 10-minute long communications sessions, or passes, 3-4 times a day. Thus communications with a LEO satellite is currently unavailable for long periods of time. Further, this limited availability is rigidly set in advance by the characteristics of the LEO orbit and the location of the supporting earth stations. Building on the global coverage of the Inmarsat I4 geo-synchronous satellite constellation and its Broadband Global Area Network (BGAN) global ground infrastructure, the Addvalue IDRS is an innovative way to provide low-latency, 24/7 cost effective data communications services to support LEO satellite operations with a real-time, consistent IP based data communications service. It will greatly enhance if not supplant current earth station networks for many LEO satellite missions with on-demand two-way connectivity to LEO satellites, thereby avoiding prohibitively high upfront investment cost and risk to deploy new satellite relay constellations or new earth stations.

Keywords: IDRS, Data-relay, Near-real-time, Secure

Acronyms/Abbreviations

Internet of Things (IOT);
Automatic Identification System (AIS);
Earth Observation (EO)
Swift Broadband for Satellites (SB-SAT);
Satellite Access Station (SAS);

1. INTRODUCTION

Communications services in support of LEO satellite operations are currently provided to a rigid time schedule based upon the particular LEO satellite orbit and the geographic location of the supporting network of earth stations. Thus communications with a LEO satellite need to be scheduled in advance, is limited to typically 3-4 intervals a day of 10 minutes duration, and is unavailable for long periods of time. This limits real-time command and control over the LEO satellite and prohibits real-time response in the face of satellite anomalies.

At the mission level this forces EO satellite operators to use scripted tasking commands that are transmitted to the satellite during a ground station pass, well in advance of the satellite visit to the geographical area of interest. The result is a latency of a number of hours to a day from order to delivery of an image to the customer.

Other satellite missions, such as IOT, AIS or weather data collection, are limited to a Store-and-Forward operation, whereby the LEO satellite stores the collected data until the next pass over a ground station.

These problems disappear with the introduction of the real-time on-demand IDRS link. IDRS is an on-demand consistent 24/7 two way data service specifically tailored to the needs of LEO satellite operations.

2. BACKGROUND

In 2010 Inmarsat was contracted by USA's Defence Advanced Research Projects Agency (DARPA) to develop a data relay system for servicing LEO satellites based on the global coverage of the Inmarsat-4 geo-synchronous satellite constellation and its BGAN global ground network infrastructure. The system, termed SB-SAT, was designed as a variant of the Inmarsat Swift Broadband aeronautical mobile satellite service and was adapted to the dynamics and altitudes of a LEO spacecraft.

In 2014 Addvalue took note of the fundamental shortfalls of the current communications means used by LEO satellites, and its engineering team began to explore the feasibility of implementing a compact, low-mass, space-resilient and affordable communications terminal that would fit to LEO satellites of all sizes starting from 6-U Nano-satellites. This terminal is a core element of a commercial data relay service, termed IDRS for supporting LEO satellite operations. Using their experience as a long established provider of Inmarsat compatible mobile satellite terminals, the Addvalue team quickly determined that such an IDRS terminal was feasible and that Addvalue had the expertise to successfully develop this new service. With the support of the Office for Space Technology and Industry (OSTIn) of the Singapore Economic Development Board (EDB) and in conjunction with Inmarsat, Addvalue began the development of a space-resilient IDRS terminal for LEO satellites.

An intermediate milestone of this endeavour was the realization of a Proof of Concept Mission: the Velox-II Project. Velox II is a 6-U Nano-size LEO satellite carrying an Addvalue produced IDRS transceiver module to conduct in-orbit technical trials of the IDRS service. Developed in collaboration with Nanyang Technological University (NTU), and with support from Inmarsat, the Velox-II was launched in December 2015 and underwent over a year of in-orbit tests. These extensive in-orbit tests fully demonstrated the IDRS system and terminal design and the operational viability of the IDRS service. The trials covered numerous real-time on-demand connectivity sessions between the Addvalue ground team and the satellite, including telnet data sessions, FTP file transfers to and from the satellite, and even an IDRS transceiver firmware upload and upgrade while in-orbit.

3. THE IDRS SYSTEM

The IDRS system consists of three key elements: the Inmarsat I-4 constellation of GEO satellites; the BGAN network and service infrastructure; and the IDRS terminal hardware and software fitted on the LEO spacecraft. The Inmarsat I-4 constellation includes 4 geo-synchronous satellites, together providing a continuous global coverage. These satellites provide communications services to user equipment at L-Band frequencies using a combination of global, regional, and spot beams. Originally designed to service ground, maritime, and aeronautical users, the BGAN system and ground infrastructure have been adapted to support the dynamics and altitudes of the IDRS terminal fitted on a LEO spacecraft.

The IDRS terminal interacts with the Inmarsat I-4 constellation and BGAN ground network in a similar way to a ground terminal but with the necessary adjustments to spacecraft dynamics and altitude. The IDRS system relies on the terminal to adjust its transmit and receive characteristics to interwork seamlessly with the BGAN TDM/F-TDMA air-interface, thereby benefiting from the maturity and heritage of the BGAN communications system and ground infrastructure. The IDRS system takes advantage of the coverage provided by the Inmarsat I-4 constellation, which is not limited to the earth surface but extends significantly into space. In other words the IDRS terminals are able to take advantage of their high altitudes and benefit from this extended coverage. Figure 1 provides a generic polar view of the Inmarsat-4 constellation and illustrates the extended coverage provided by the Inmarsat-4 outer ring of spot beams (coloured in green). The coverage offered to the IDRS terminal depends on the LEO satellite altitude and inclination. Spacecraft below Mid-LEO altitudes would benefit from 80% and up to 100% coverage.

The IDRS system overview is illustrated in Figure 2. The LEO spacecraft maintains near real-time Full Duplex connectivity with the Inmarsat Data Connection Network via the IDRS Service Link to one of the visible Inmarsat-4 satellites and via the corresponding Feeder Link to one of the Inmarsat SAS's. The radio link between the IDRS terminal and the ground is secure and protected by a 3G-Cyphering protocol. The end-to-end IP data connection between the customer premises and LEO spacecraft is carried securely over the global and private Inmarsat Data Connection Network. The final connection to the Customer Mission Control is carried securely either via VPN over open internet, or via a leased line.

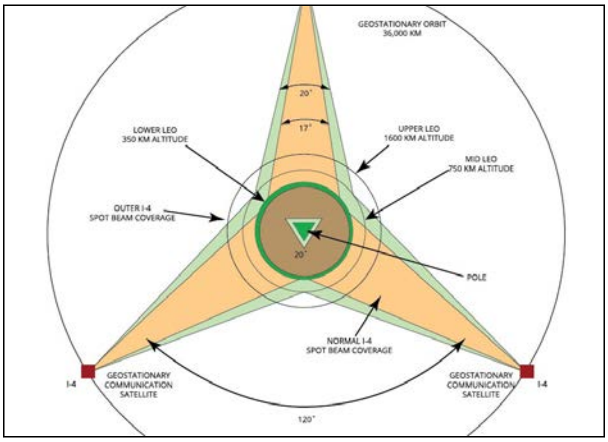

Figure 1 The IDRS System Concept – Polar View

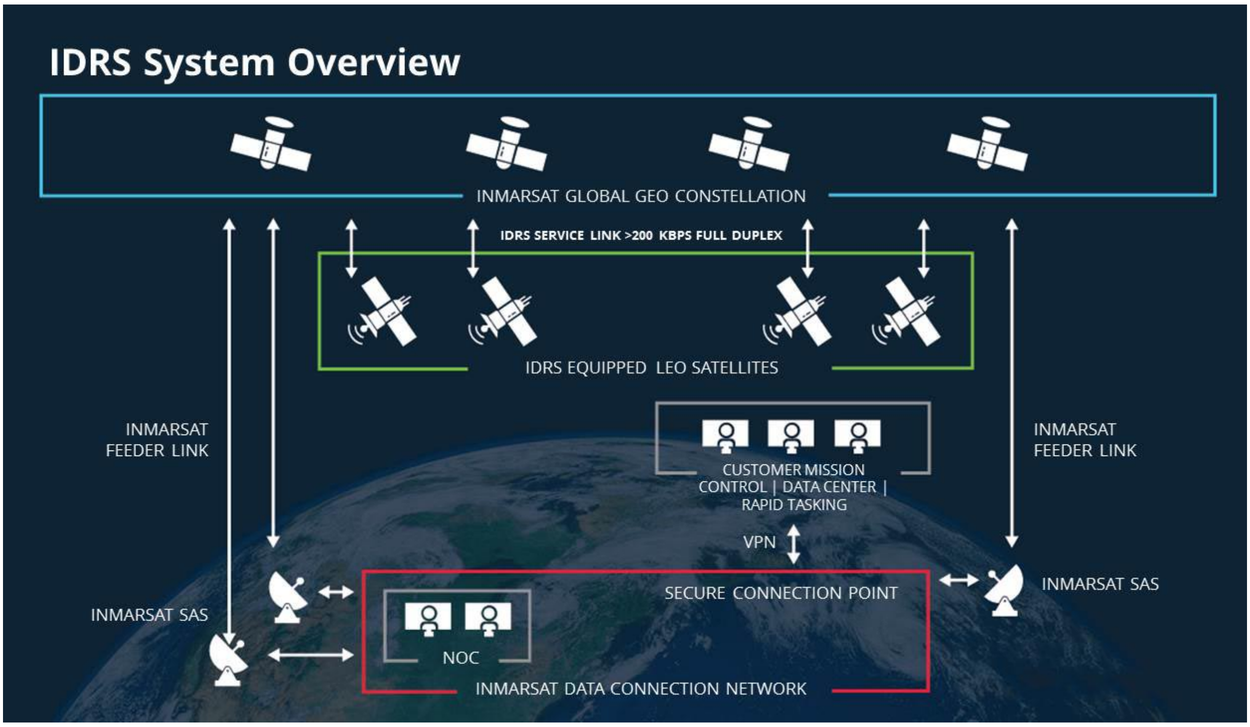

Figure 2 IDRS System Overview

Each of the IDRS terminals is assigned a static IP address and its location is tracked by the mobility management function of the BGAN network. This allows instant connectivity to be initiated "On Demand" either by the LEO spacecraft or by Mission Control on the surface.

4. THE IDRS SERVICE CAPABILITIES

4.1 Mobility Management:

The mobility management function of the Inmarsat BGAN network ensures that the IDRS terminal will maintain IP session continuity when rapidly transiting through the Inmarsat-4 traffic spot beams. There would be only a short interruption during a handover between Inmarsat-4 satellites which would take less than 30 seconds due to re-acquisition / re-registration to the BGAN network.

4.2 Latency:

The End-to-end latency between the IDRS terminal on the LEO spacecraft and the Mission Control ranges between 0.5 and 1.5 seconds.

4.3 Connection Availability and Reliability:

The IDRS service benefits from the maturity and reliability of the Inmarsat BGAN network which maintains network availability of 99.5% through the use of dual SAS redundancy. The IDRS radio link budget availability is maintained higher than 99%, as the rate adapted protocol stack maintains the minimum required link margin.

4.4 Data Rates:

The IDRS forward link (ground to LEO spacecraft) supports data rates ranging between 200 and 300 kbps with a typical data rate of 250 kbps. The return link (LEO spacecraft to ground) supports data rates between 96 and 250 kbps with a typical data rate of 200 kbps.

5. THE IDRS TERMINAL

The IDRS terminal has been designed by Addvalue as a compact, low-mass, space-resilient and affordable communications terminal that would fit to LEO satellites of all sizes starting from 6-U Nano-satellites. The terminal is a core element in the IDRS data relay service for supporting LEO satellite operations.

Antenna Type	Directional Antenna	Switched Antenna	Omni Antenna
Antenna Dimensions	Patch Ant. 200mm x 100mm	7 Segment Ant. 150mm x 270mm Or attached to top and side panels	ISOFLUX Ant. element 200mm x 20mm (Height x Diameter)
Transceiver type	i100 (1U)		
Transceiver Dimensions	125 x 96 x 70 mm^3		
Transceiver Weight	< 1Kg		
Antenna Design			
Antenna Weight	<150g	<2.8kg (incl Switching Module)	<1.2kg (incl Front-end Module)

Table 1 The IDRS i100 Terminal Overview

5.1 IDRS i100

Figure 3 provides an image of the i100 transceiver.

Figure 3 The IDRS i100 Transceiver

The IDRS i100 terminal is designed to match the requirements of small LEO satellites down to 6-U Nano-satellites. The terminal is designed with an operational lifetime of 3 years in space. The terminal consists of a transceiver module plus one of three optional antenna configurations to match different satellite constraints, orbital characteristics and mission requirements. An overview of the terminal dimensioning is provided in Table 1.

In the meanwhile, in order to match the requirements of high-end LEO satellites with an operational lifetime of 7 years in space, a variant of the IDRS terminal is being designed with a similar functional performance but at a much higher space resilience specification.

The power consumption characteristics for the IDRS i100 terminal is summarized below:

Rx mode: < 7 Watts
Tx mode:
- Omni Ant: < 40 Watts Peak
- Switched Ant: < 32 Watts Peak
- Directional Ant: < 25 Watts Peak

Average (TT&C + Tasking → 10% duty cycle)
- Omni Ant: <10.3 Watts
- Switched Ant: < 9.5 Watts
- Directional Ant: < 8.8 Watts

IDRS – APPLICATIONS AND BENEFITS

The "always-on" communications capability offered by IDRS can be a "game-changer" for LEO satellite missions by simplifying and at the same time enhancing the concept of operations for LEO missions in a number of domains:

6.1 Near-real-time TT&C:

With IDRS an anomaly on board the LEO satellite can be automatically reported back to its operator for diagnosis and quick restoration of LEO satellite service. Also, with real-time IDRS connectivity the cost and duration of the commissioning period for new LEO satellites is greatly reduced.

6.2 Near-Real-Time Tasking / Re-Tasking

IDRS supports a near-real-time delivery of tasking and re-tasking data to earth observation LEO satellites which can significantly shorten the latency between order and delivery of the collected images, thereby significantly increasing the value of the image for time sensitive mission types such as surveillance, defence and "responsive space".

6.3 Near-Real-Time Delivery of Mission Data

IDRS supports applications that need on-demand connectivity sessions and longer sessions than the 'fly-over-earth-station' time slot. Then there is the opportunity to enhance data collection through coordinated tasking over a LEO constellation for more sophisticated missions. The need for more real-time communications among these LEO satellites operating in a coordinated manner is crucial for such operations.

6.4 Augmentation of Earth Station Network Services

The IDRS service can augment earth station networks currently used by LEO satellite missions by extending service availability through real-time LEO satellite connectivity.

6.5 Support of Launch Services

IDRS offers near-real-time connectivity to launch vehicles and space transport thereby providing economic temporary down range facilities where such facilities are not readily available, for example over oceanic launch trajectories.

6. CONCLUSIONS

Addvalue offers the IDRS service to LEO satellite operators on a global basis. The IDRS product consists of space qualified hardware and a data relay service offering based on access to the global Inmarsat BGAN network. Operators can contract for the satellite hardware through their LEO satellite procurement and contract with Addvalue for network operational airtime on a usage basis. The commercial, fully space qualified IDRS product is on offer now.