DEVELOPMENTS IN SATELLITE COMMUNICATION SYSTEMS

USEFUL SATELLITE SYSTEMS FOR DATA BUOY OPERATORS

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Summary and purpose of document

This document, prepared by David Meldrum (Scottish Association for Marine Science) provides an overview of the current status of mobile satellite systems, as well as their actual or potential application to data buoy operations and data collection, updated in February 2008.

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1. Introduction

This paper describes the types of satellite communications systems available for use by data buoy operators. The individual groupings GEO, MEO and LEO satellites types are explained and within each of these groupings the major satellite systems are described. Some useful resources are given and then an overview of all mobile satellite systems which currently offer data buoy applications is tabulated.

2. Description of Satellite types

Satellite systems may be classified according to orbit altitude as follows:

- GEO - geostationary earth orbit, approx altitude: 35 000 km
- MEO - mid-altitude earth orbit, approx altitude: 10 000 km
- LEO - low earth orbit, approx altitude: <1 000 km

LEOs can be further sub-divided into Big LEO and Little LEO categories. Big LEOs offer voice, fax, telex, paging and data capability, whereas little LEOs offer data capability only, either on a real-time direct readout ('bent pipe') basis, or as a store-and-forward service.

Since the satellite footprint decreases in size as the orbit gets lower, LEO and MEO systems require larger constellations than GEO satellites in order to achieve global coverage and avoid data delays. Less energy is, however, generally required for LEO and MEO satellite communication because of the shorter average distance between transmitter and satellite. Some systems implement several high-gain antennas to generate ‘spot beams’ and so reduce the requirement of the mobile to have a complex antenna and/or high output power. Another trend is towards much smaller and cheaper satellites: minisats, microsats, nanosats, picosats and even femtosats — credit-card-sized satellites.

Due to the commercial forces which are driving the implementation of the new systems, many will primarily focus on land masses and centres of population, and will not offer truly global or polar coverage. These systems will not in general be acceptable for global ocean monitoring. Furthermore, while the technical capabilities for the new systems do currently exist, delays are inevitable due to problems with spectrum allocation, licensing (in each country where the service will be offered), company financing, and availability of launch vehicles and ground stations.

It is unlikely that all of the planned systems will overcome all of these hurdles. Indeed, major financial difficulties have hit a number of systems, including Iridium, Orbcomm and Globalstar. Mergers are becoming increasingly common, as market reality forces system planners to cut their losses and pool resources.

From a technical point of view, some new systems do offer significantly enhanced capabilities compared to traditional carriers. Potential advantages include two-way communication, more timely observations, and greater data rates and volumes. Some systems are also proving to be considerably less expensive and more energy efficient than traditional channels. However, dangers will exist for data buoy users of most systems, in that they will generally be small minority users of the system, with consequent lack of influence in regard to pricing. The arrangements for data distribution are also unlikely to be tailored towards data buoy applications, in particular those that require data insertion onto the GTS.

The DBCP has been active in this regard through its establishment of the Iridium Pilot Project as an end-to-end evaluation of the suitability of the Iridium satellite system for the collection, processing and GTS insertion of drifter data.

3. Description of Candidate Satellite Systems

The following paragraphs describe the salient features of those systems that might have a data buoy application. This section is summarised in tabular form in the Annex of the document. Systems which are deemed to have failed have been removed from the main text, but remain in the summary table.

3.1 Little LEOs

3.1.1 Argos

Argos has been used by the oceanographic community for nearly three decades, and is a dependable, true polar, operational data collection and platform location system. Traditionally, communication is one-way only, at 400 baud, with practicable data rates of the order of 1 kbyte per day. Transmissions by the mobile in this mode are unacknowledged by the system and therefore have to incorporate redundancy if data transfer is to be assured. The system enjoys a particularly clean part of the spectrum (401.65 MHz), with minimal interference from other users. Until recently, Argos has flown as an attached payload on the NOAA 'TIROS' weather satellites, but also flew on board the short-lived Japanese ADEOS-II vehicle. It has also been successfully launched on board the European METOP-1 vehicle. Further projected launches on board the METOP series and future US NPOESS platforms mark an important diversification of service provision.

Current enhancements to the Argos on board equipment ('Argos-2') include increased receiver bandwidth and sensitivity, allowing low power transmitter frequencies to be segregated from higher power transmissions. Next generation Argos equipment ('Argos 3') is flying on METOP-1, with future launches planned for 2010 and 2014. Argos-3 features two-way communication with Platform Messaging Transceivers (PMTs), and offers uplink data rates of up to 4.8 kbits/ s. The downlink feature allows the Argos-3 instrument to send an acknowledgement signal to the PMT once the data are received error-free, thus permitting the PMT to avoid unnecessary repetition of the same message. Platform remote control and programming is also possible as users have the opportunity to send short messages (up to 128 bits) to their platforms via the Downlink Message Management Centre (DMMC).

The system is one of the few that offers true global coverage, and currently has no commercial requirement to recover the cost of the launch or space segment equipment. collected. Main ground stations, capable of retrieving data from a complete orbit, are located in the eastern US and Alaska. A third station in Svalbard is shortly to be brought on line to take data from those orbits that are not seen by the existing pair of stations. The main stations are supplemented by 50 direct readout stations, which receive data rebroadcast by the satellite in real time. This continues the programme of improving data timeliness by exploiting the use of Argos in 'bent-pipe' mode.

3.1.2 ORBCOMM

This company was awarded the first FCC Little-LEO licence in late 1994. Satellites consist of discs about one metre in diameter prior to deployment of solar panels and antenna. Two satellites were launched into polar orbit during 1995, using a Pegasus rocket piggy-backed on to a Lockheed L-1011 aircraft. Orbcomm have been awarded a licence for eventual expansion to a 48 satellite constellation. Currently 29 satellites are operational. The A, B, C and D planes are at 45° inclination and therefore have poor coverage at high latitudes: only one elderly satellite, in the G plane (70°), offers a near-polar service. In Mar 2005 the company announced a new launch programme that would carry an Automatic Identification System (AIS) payload, transmitting ship identification and position for use by the US Coast Guard. In July 2006, Orbcomm ordered 6 satellites from OHB System AG. The satellite buses and launch procedures are to be handled by Omsk, Russia, with Orbital Sciences Corporation (OSC) providing the communication payloads and AIS processing.

The system offers both bent-pipe and store-and-forward two-way messaging capabilities, operating in the VHF (138-148 MHz) band. User terminals are known as ‘Subscriber Communicators’ (SCs). Early results with the system were quite encouraging, although data buoy implementations seem to have decreased in favour of increased usage of Iridium for higher bandwidth applications.

The message structure currently consists of packets transmitted at 2400 bps (scheduled to rise to 4800 bps), and coverage is now global and near-continuous between the polar circles. Messages are acknowledged by the system when correctly received and delivered to a user-nominated mailbox. The platform position is determined, if required, using propagation delay data and doppler shift, or by an on-board GPS receiver. Position accuracy without GPS is similar to that offered by Argos, i.e. km-scale.

The limitations on the store-and-forward mode messages (known as globalgrams) have become apparent, with SC originated messages limited to 229 bytes and SC terminated messages limited to 182 bytes. Each SC can theoretically have a maximum of 16 globalgrams stored on each satellite. Currently, satellites will not accept or process globalgrams when in view of a ground (‘gateway’) station. As messages have to be designated as globalgrams or bent-pipe by the SC at the moment of origination, this presently limits the flexibility of the system to adapt to different coverage situations. Work-arounds do, however, exist, and it is expected that the next generation of SCs will be able to adapt more readily to changes in satellite communications mode.

The ground segment has continued to expand, and there are now active stations in Italy, Morocco, Argentina, Brazil, Curacao, Japan, Malaysia and Korea in addition to the four in the US. However the Japanese station is not available for international registrations. Further potential sites have been identified in Russia, Ukraine, Philippines, Botswana, Australia and Oman, though these have yet to be implemented. 16 international service distribution partners have been licensed. Non-US customers have faced considerable difficulties because of the absence of ground stations, lack of spectrum licensing and the presence of other in-band users. However the situation is improving.

3.2 Big and Broadband LEOs

3.2.1 Iridium

Iridium filed for Chapter 11 bankruptcy protection in August 1999, and underwent financial restructuring. Financial difficulties continued and the system ceased operation in April 2000. At that time, Iridium had its complete constellation of 66 satellites plus spares in orbit, and offered a true global service through a network of ground stations backed up by inter-satellite links. The system has since been rescued from planned de-orbiting and resurrected by the US Department of Defense. A commercial service has also been relaunched. Most Iridium phones are data capable and will communicate with a standard modem. Throughput is about 2400bps. The component parts of some phones are now being repackaged as stand-alone modems. A short burst data (SBD) service (~1900 bytes max per message) was introduced in late 2002, as well as a dropout-tolerant direct Internet connection at up to 10kbps.

Of particular interest to data buoy operators in the early days of Iridium was the Motorola L-band transceiver module, which was designed to be easily integrated with sensor electronics via a standard serial interface. This product has now reappeared as the Motorola 9522 modem, and is capable of both dial-up and data-only modes of operation.

The SBD service offers an easily implemented solution for the transfer of a few kbytes of data per day, transactions taking place as conventional e-mails and attachments. The system is bidirectional and messages may also be queued for the mobile. The cost is currently ~$1.50/kbyte, plus a monthly fee. The new 9601 SBD modem offers simple interfacing, compact size and modest prices (about $400), and has a recently upgraded maximum message size of 340 bytes. Dial-up remains the better option for larger volumes of data, with costs capable of falling below $0.1/kbyte. Energy costs are also low for both modes of access (~20J/kbyte), largely because of continuous satellite availability and the implementation of spotbeams to reduce the mobile transmitter power requirement.

A new ‘near broadband’ product has also been announced, expected to offer transfer rates of about 100kbps at an undisclosed cost. Discussions are also underway regarding special tariffs for scientific and environmental users, and CLS have entered the arena as potential service providers (Value Added Resellers) for this category of use.

3.2.2 Globalstar

Globalstar was Iridium’s main competitor in the mobile satellite telephony market. The company's voice and data products include mobile and fixed satellite units, simplex and duplex satellite data modems and flexible service packages. After a bad start in September 1998 when 12 satellites were lost in a single launch failure, Globalstar now has its complete 48 satellite constellation in space, and commenced a limited commercial service in the US in October 1999. Service has since been expanding to other regions and was available in the UK in mid 2000. Globalstar differs significantly from Iridium in that for a call to be made the user must be in the same satellite footprint as a gateway station. There is no inter-satellite relay capability as in Iridium. This means that coverage will not be truly global, especially in the short term as far fewer gateways have been built than originally planned. Although Globalstar was currently in a much stronger financial position than any of its competitors, only 55,000 subscribers had been signed by late 2001 and the company laid off half of its work force in August 2001. Globalstar subsequently filed for Chapter 11 bankruptcy protection in February 2002. The company has now been taken over by Thermo Capital Partners LLC. Recently in March 2006 Globalstar announced to have 200,000 customers using their satellite voice and data services. Moreover, Globalstar has also announced an agreement with Qualcomm to manufacture its current and next generation handset. Globalstar added eight first-generation satellites in 2007 as it manages the transition through to the launch of the Globalstar II second-generation constellation, which is expected to begin in late 2009..

Data services at 9600 bps are now available, using a dedicated modem. Moreover, Globalstar announced that it has partnered with satellite communications ocean software and hardware company, OCENS, to launch a comprehensive suite of data services. This would now improve data compression rates with effective data transfer speeds of up to 56 kbps. Globalstar also has a second generation system planned, said to involve 56 LEO satellites and 5 GEO satellites.

3.3 GEOs

3.3.1 Inmarsat D+

This is an extension of the Inmarsat D service using the new (spot-beam) Inmarsat Phase 3 satellites and small, low-power user terminals. The system was initially designed as a global pager or data broadcast service, with the return path from the mobile used only as an acknowledgement. D+ permits greater flexibility, but the uplink packets are still limited to 128 bits. The first ground station has been implemented in the Netherlands by the existing Inmarsat service provider (Station 12), but useful technical information has been difficult to obtain. The only remaining manufacturer of D+ transceiver seems to be Skywave. The Skywave unit includes an integral antenna and is specifically designed for low power applications.

The service may prove particularly attractive to national meteorological services as protocols already exist with Inmarsat service providers for the free transmission of observational data to meteorological centres for quality control and insertion on to the GTS. Inmarsat, given its assured multinational backing and established infrastructure, is also extremely unlikely to disappear.

3.3.2 Inmarsat Broadband Global Area Network (BGAN)

Inmarsat Broadband Global Area Network (BGAN) offers a mobile communication service which provides both voice and broadband data simultaneously through a portable device, on a near-global basis. BGAN service is accessible via a range of small, lightweight satellite terminals with an option of single user or a small team. The terminals may be connected to a laptop through wired or wireless connections including BlueTooth and WiFi. BGAN delivers Internet and intranet content and solutions, video-on-demand, videoconferencing, fax e-mail, phone and LAN access at speeds of up to 492 kbps. Moreover, it supports both circuit-switched and packet-switched voice and data services. It uses the new (spot-beam) Inmarsat-4 (I-4) satellites which were launched in late 2005.The first two of three I-4 satellites are commercially operational in Inmarsat's Indian and Atlantic ocean regions, with coverage extending across North and South America, Europe, Africa and the Far East. The third launch of the Inmarsat-4 has yet to be determined.

There are many different airtime price plans available with the BGAN service, some of them cost less then a dollar for a low-cost voice call for a minute, combined with high-speed data and Internet connectivity, in a 'go anywhere' satellite terminal. The service is distributed by some of the leading distributors such as BT, UK, France Telecom Mobile Satellite Communications, France, Stratos, USA, Telenor Satellite services, Norway and USA etc.

3.3.3 New ICO (MSS/ATC service)

On May 24, 2005 the FCC granted New ICO a request to modify their reservation of spectrum for the provision of mobile satellite system (MSS) services in the United States using a GEO satellite system, rather than a MEO satellite system. Their MSS/ATC System infrastructure is expected to include one orbiting GEO satellite, which will utilize a "bent pipe" architecture, a ground-based beam forming (GBBF) equipment that is expected to be located at the gateway ground station, a land-based transmitting/receiving station, a core switching/routing segment, an ancillary terrestrial component and finally end-user equipment capable of supporting satellite-only and dual-mode (satellite/terrestrial) services.

Initial steps have been taken wherein New ICO has entered into a contract with Loral for construction of GEO in Jan 2005. Loral has completed the satellite critical design review in May 2005, and physical construction of the satellite is currently underway. The launch for the same is planned for July 2007.

The GEO satellite is designed to provide continuous service coverage primarily in all 50 states in the United States, as well as Puerto Rico and the U.S. Virgin Islands. If appropriate regulatory approval is granted by other countries, the GEO satellite is also capable of providing service outside of the United States, throughout many parts of North America.

3.3.4 GOES, METEOSAT, etc

These GEOs exist primarily to collect and disseminate weather imagery, but do also support low-rate data collection systems. Access to the satellites is controlled by pre-allocated time-slots, and the service is largely free. The requirement for significant transmitter powers and/or directional antennae has tended to restrict applications to larger data buoys, although some success has been reported with lower power installations. MTSAT 1R, MTSAT 2 METEOSAT 9, GOES-13 were the satellites launched in the year 2005 & 06 for meteorological studies.

3.3.5 Inmarsat Mini-M, Inmarsat C & Mini-C, Thuraya, ACes, AMSC, etc

These advanced GEOs offer voice-band communications using compact handsets or laptops by implementing high gain steerable spot beams to achieve sufficient link margin. Data services may available using a modem connection on the handset. Coverage is generally regional and not advertised for oceanic areas.

4 Useful Web Sites

4.1 General information

Little LEO status, launch dates	http://centaur.sstl.co.uk/SSHP/const_list.html
Constellation overview	http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations
The Satellite Encyclopedia (subscription required)	http://www.tbs-satellite.com/tse/online
General satellite news/gossip	http://www.hearsat.org
Satellite news	http://www.spacedaily.com
General space news	http://www.space.com/spacenews

4.2 Specific operators

Argos	http://www.cls.fr & http://www.clsamerica.com
Globalstar	http://www.globalstar.com
GOES	http://www.goes.noaa.gov
Inmarsat	http://www.inmarsat.com
Inmarsat BGAN	http://broadband.inmarsat.com
Iridium	http://www.iridium.com
METEOSAT	http://www.eumetsat.int
ICO	http://www.ico.com
Orbcomm	http://www.orbcomm.com

4.3 Data Buoy Cooperation Panel

Data Buoy Cooperation Panel	http://www.jcommops.org/dbcp
DBCP Iridium Pilot Project	http://www.jcommops.org/dbcp/iridium-pp/

5 Overview of mobile satellite systems with possible data buoy applications

System	Status*	Date (if known)	Orbit type	Buoy position	Message type	Terminal size	Power (W)	Comments
APRIZESAT	Operational		Little LEO	GPS required	data: TBD	Handheld	7	4 nanosatellites in orbit, 2-way comms, directed at asset tracking
ARGOS	Operational		Little LEO	Doppler Shift	data: 32 bytes	Handheld	1	Various enhancements, incl 2-way messaging with PMTs, are scheduled under Argos 3. Launch of MetOp-A in Oct 06.
ECCO (CCI Global)	Cancelled (pre-op)		LEO	GPS required	voice/data	Handheld	TBD	12 equatorial satellites planned by 2003. Status questionable – merged with ICO-Teledesic Global
ELLIPSO	Cancelled		Big LEO	GPS required	voice/data	Handheld	TBD	17 satellites in highly elliptical orbits, serving major land masses. Status questionable – merged with ICO-Teledesic Global
EYESAT	Experimental		Little LEO	GPS required	data: 60 bytes	Handheld	5	1 satellite 1995, principally for radio amateurs
E-SAT			Little LEO	GPS required	data: TBD	TBD		6 satellites for utility metering (aimed at Continental US only initially)
FAISAT	Cancelled	2002	Little LEO	GPS required	data: 128 bytes	Handheld	10	38 satellites 2000+ Test satellite launched 1997. Final Analysis Inc is terminated in bankruptcy.and assets sold to New York Satellite Industries LLC.
GEMNET	Cancelled (pre-op)		Little LEO	GPS required	data: no maximum	Laptop	10	1st satellite 1995 - launch failure 36 satellites by ???
Globalstar	Operational	1999	Big LEO	GPS required	voice/data: no maximum	Handheld	1	48 satellites + spares (constellation complete) . 2nd generation system comprising of 56 LEO satellites and 5 GEO satellites. Launch of their eight spare satellites, completed 2007.

GOES, Meteosat, GMS	Operational		GEO	GPS required	data: various options	Laptop	10	5 satellites; directional antenna desirable NOAA / ESA / Japanese met satellites.
GONETS-D	Pre-operational. On-hold		Little LEO	GPS/ Glonass	Data	Handheld	TBD	8 satellites in orbit, 36 more planned. Most probably test satellites.
GONETS-D1	Operational		Little LEO	GPS/ Glonass	Data	Handheld	TBD	9 satellites in orbit.
GONETS-D1M1	Operational		Little LEO	GPS/ Glonass	Data	Handheld	TBD	Launched in Dec 05. First of a fleet of 12 satellites in 4 planes.
GONETS-R	Cancelled (pre-op)		Little LEO	GPS/ Glonass	Data	Handheld	TBD	48 satellites planned. Lack of commercial interest.
INMARSAT-C	Operational		GEO	GPS required	data: no maximum	5.5 kg	15	Steered antenna not required
INMARSAT-D+	Operational		GEO	GPS required	data: 128bytes uplink, 8 bytes downlink	Handheld	1	Global pager using existing Inmarsat-3 satellites Note very oriented to downlink
INMARSAT-Mini-M	Operational		GEO	GPS required	voice/data: no maximum	Laptop	1	Mobile phone using regional spot-beams
INMARSAT-Mini-C	Operational		GEO	Built-in GPS/	Email data	Handheld	1	Steered antenna not required. Typicaly used in remote monitoring and, in combination with web-based tracking.
ICO (New ICO)	20 MHz Licensed allotted	Dec 2005	MEO	GPS required	voice/data: no maximum	Handheld	1	Global voice and packet data services. 12 satellites planned, only one launched so far.They have 10 satellites in advanced stages of completion.
ICO (New ICO)	Planned	May 2005	GEO	GPS required	voice/data: no maximum	Handheld	TBD	One GEO orbiting satellite to be launched in July 2007. ICO G1 satellitelaunch planned for April 2008. Intially would cover US states.

Iridium	Revived	July 2005	Big LEO	GPS preferred	voice/data: no maximum	Handheld	1	66 satellites plus 7 backup and had 11 orbital storage.
IRIS/LLMS	Experimental On hold		Little LEO	Doppler + Ranging	data: up to few kbytes	Handheld	1	1 satellite in orbit. Belgian messaging system part of an ESA research prog.
LEO One	Licensed On hold	Service mid 2003	Little LEO	GPS required	data: uplink 9600bps, downlink 2400bps	Handheld	Max 7	48 satellite constellation, store and forward + 8 spares. No polar sats
LEO SAT Courier	Planned On hold?	Service 2003+	Big LEO	GPS required	Data / voice	Handheld	1-5	72 satellites
OCEAN-NET	Experimental		GEO	Moored	no maximum	Large		uses moored buoys + Intelsat
Ocean DataLink (ODL)	Experimental On hold?		GEO	GPS	no maximum	Handheld	TBD	uses Intelsat
Odyssey	Cancelled (pre-op)		MEO	GPS required	voice/data: no maximum	Handheld	1	12 satellites were planned
ORBCOMM	Operational	1998	Little LEO	Doppler or GPS	data: no maximum	Handheld	5	35 satellites in orbit, 30 operational, expansion to 48 sats licensed. 6 satellites from OHB System AG.
SAFIR	Pre-operational On hold		Little LEO	Doppler or GPS	data: no maximum	Laptop	5	2 satellites in orbit
Signal	Planned On hold?		Big LEO		voice/data			48 satellites planned
SkyBridge	Cancelled (pre-op)	Service 2002+	Big LEO	GPS required	Broadband	Larger than handheld		80 satellites planned, recycling GEO spectrum allocations
Starsys	Cancelled (pre-op)		Little LEO	Doppler + ranging	data: 27 bytes multiple msgs	Handheld	2	12 satellites 1998+ 24 satellites 2000+

Teledesic	Cancelled (pre-op)	Service Late 2004	Big LEO	GPS required	Broadband			
Temisat	Experimental		Little LEO		Data			7 satellites planned for environmental data relay. 1 satellite launched 1993.
Thuraya	Operational		GEO	Integral GPS	Voice/data	Handheld		Thuraya 1 & 2 with multiple spot beam satellite in orbit (over Middle East), Thuraya 3 planned.
Vitasat	Pre-operational, on-hold		Little LEO	GPS required	Data			2 satellites in orbit, 2 more planned
WEST	Planned On hold	Service 2003+	MEO	GPS required	Broadband			9 satellites planned

* Status of systems is categorized according to seven groups:

Planned: Little is known about the system except a name, notional type, and services to be offered. Mostly not licensed, although some may be.
Licensed: System has been licensed by a national or international regulatory agency (in most cases the FCC), but no satellites have been launched.
Experimental: System has one or more satellites in orbit for experimental purposes (not usually part of the final constellation). Includes new systems planning to use existing satellites.
Pre-operational: System is in process of launching, or has launched, its constellation but is not yet offering full services. Some limited evaluation service may be available.
Operational: System has full or nearly full constellation in place and is offering readily available service to external users (not necessarily commercial).
Cancelled: System has been cancelled, either before satellites launched (pre-op) or after (post-op).
On hold: No progress reported or scheduled.

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