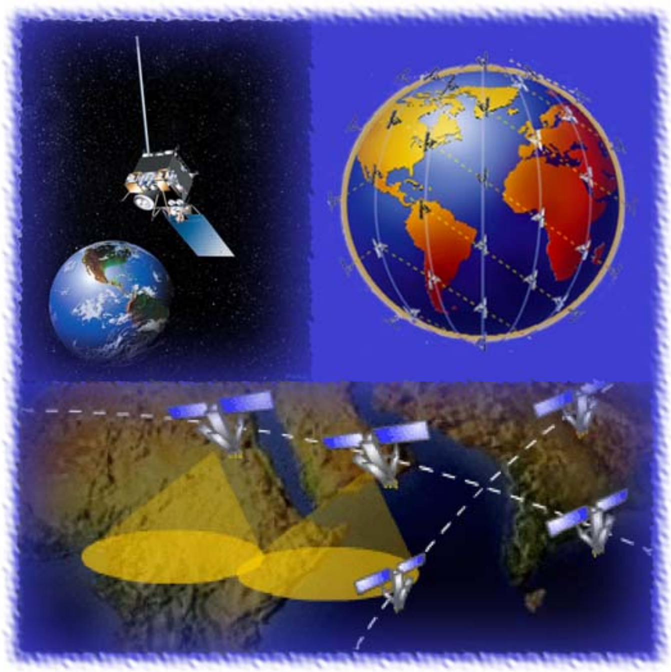
Ocean Systems Test and Evaluation Program

Data Communications Plan



May 2006

noaa **National Oceanic and Atmospheric Administration**

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services

National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The Center for Operational Oceanographic Products and Services (CO-OPS) mission is to deliver the operational environmental products and services necessary to support the National Oceanic and Atmospheric Administration's (NOAA's) environmental stewardship and environmental assessment and prediction missions. CO-OPS provides the focus for operationally-sound observation and monitoring capability, coupled with environmental predictions to provide the quality data and information needed to support the National Ocean Service (NOS) primary goals of navigation, coastal communities, habitat, and coastal hazards.

Ocean Systems Test & Evaluation Program

The CO-OPS Ocean Systems Test and Evaluation Program (OSTEP) facilitates the transition of new technology to an operational status, selecting newly- developed sensors or systems from the research and development community and bringing them to a monitoring setting. OSTEP provides quantifiable and defensible justifications for the use of existing sensors and methods for selecting new systems. The program establishes and maintains field reference facilities where, in cooperation with other agencies facing similar challenges, devices are examined in a non-operational field setting. OSTEP evaluates sensors, develops quality control procedures, and generates maintenance routines. Rigorous, traceable calibrations and redundant sensors assure the quality of the reference systems used in the field.

The program receives guidance from the Ocean Systems Test & Evaluation Advisory Board.

OSTEP Advisory Board

Ocean Systems Test and Evaluation Program

Data Communications Plan

Tammy Graff
James Sprenke
Mark Bushnell

May 2006

National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
Carlos M. Gutierrez, Secretary

National Oceanic and Atmospheric Administration
Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (Ret.)

National Ocean Service
John H. Dunnigan, Assistant Administrator

Center for Operational Oceanographic Products and Services
Michael Szabados, Director

NOTICE

CO-OPS STATEMENT OF ACCEPTANCE

CO-OPS management personnel have reviewed this document and concur with the recommendations and conclusions herein. Technology is changing rapidly; however, the document recommendations are sufficient as described based upon the best information available.

5-25-06 | 5/25/06
OSTEP Project Leader Date | OSTEP Program Manager Date

7/26/06 | 7/25/06
Chief, Requirements & Development Date | Chief, Products & Services Date

7/26/06 | 7/25/06
Chief, Field Operations Date | Chief, Information Systems Date

7/27/06
Director, CO-OPS Date

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Executive Summary

The Center for Operational Oceanographic Products and Services (CO-OPS) supports the National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) strategic goals by providing high-quality data products and services. The raw data used for our products are obtained through the placement of measurement systems within the coastal United States and in other isolated areas. These systems enable CO-OPS to acquire, transmit, and receive data reliably, which is critical to the quality of our products and services.

Programmatic requirements and data communication technology are changing very rapidly, making it difficult but necessary for CO-OPS to effectively plan for the future. The systems that are currently used for primary and secondary data communications include geostationary operational environmental satellites (GOES), telephone lines, line-of-sight radios, and Internet protocol (IP) modems. Most of our current data communication needs are being met by GOES; however, larger data sets (such as those acquired by the acoustic Doppler current profilers or ADCP), as well as more frequent transmissions, have increased the need for a secondary satellite communications system. These operational demands, along with resource constraints, drive the data communications system requirements, which include:

- Reliable real-time data (every six minutes)
- Company/system stability
- Acceptable cost
- Ability to expand usage
- System versatility
- Two-way communication capability

The National Environmental Satellite, Data, and Information Service (NESDIS) is responsible for allocating GOES IDs to users. Over the past several years, CO-OPS has received the requested number of GOES IDs from NESDIS; however, several factors may influence our future ability to obtain sufficient GOES IDs to accommodate our growing needs. The requirement for real-time data every six-minutes increases the number and types of GOES IDs needed to meet mission goals. Other agencies, such as those involved with the Integrated Ocean Observing System (IOOS) will also have an urgent need for GOES communication in the future. NESDIS plans to increase the number of IDs by using smaller frequency buffers, but they will require a 'strong justification' from CO-OPS in order to allocate additional six-minute IDs. GOES is an important tool for data transmission; however, it does not meet all the criteria necessary for newer sensors (such as ADCPs). GOES does not offer complete global coverage and does not provide two-way communication. Therefore, each station using GOES as a primary telemetry method must also have a secondary system to provide access in case of the primary system's failure, system restarts, upgrades, or backfilling of missed transmissions.

Selection of the data communication system depends upon which of the above criteria must be met. For example, the length of time between data transmissions and the amount of data transmitted varies. Some stations may need to transmit data even more often than every six minutes, e.g. for monitoring a tsunami. The data communication system selected must be able to meet the most stringent requirements for the lowest cost, even though some stations may not fully utilize all criteria.

CO-OPS evaluated a variety of land- and satellite-based systems, including GOES, line-of-sight radios, telephone lines, Internet Protocol (IP) modems, the cellular coastal network, and commercial satellite systems. The commercial systems evaluated include Inmarsat, Inc., Iridium Satellite LLC (Limited Liability Company), ORBCOMM, Globalstar, and ARGOS. For most sensor platforms, GOES meets the stated communication needs for our applications at the lowest cost. For applications where GOES does not meet the requirements, the commercial system from Iridium Satellite LLC appears to be a great option due to its versatility on a variety of platforms and its low cost.

Although these systems appear to meet the present and near-future needs, CO-OPS must be flexible and stay abreast of the emerging data communication technologies, keeping options open in order to take advantage of the newest developments.

1.0 Introduction

1.1 Purpose of this Report

Data communication systems play a critical role in CO-OPS' ability to acquire and transmit water level, current, and other oceanographic and atmospheric data. These data are the basis for many CO-OPS high-quality products that help us achieve our goal of ensuring safe and cost-efficient navigation, while also providing information that supports search and rescue, weather predictions, and other NOAA strategic goals. Currently, the data collection service available on NOAA's GOES (geostationary operational environmental satellites) operated by the NOAA National Environmental Satellite Data and Information Service Data Collection System (NOAA/NESDIS/DCS) is used for most data transmittals. However, we anticipate a large growth in the number of stations requiring the transmittal of data every six minutes. The ability of the GOES system to fully meet these needs is hopeful but uncertain. Additionally, a secondary satellite system is needed to complement the GOES system for applications where its use is impossible due to geographic location, power constrictions, or other circumstances of the installation.

This document examines the data communications systems that CO-OPS currently employs and assesses the ability of the current GOES system to meet future needs through the year 2012. Additionally, requirements for supplementary data communications options are identified and existing systems are evaluated to determine their ability to meet these needs. Finally, recommendations are made for future actions to be taken to ensure our ability to meet our growing data communications needs.

1.2 Background

Remote sensors, located somewhat evenly along the east and west coasts of the continental United States (U.S.) (as well as in Alaska, Hawaii, Pacific Islands, the Gulf of Mexico, and the Caribbean), acquire data that are transmitted to a data collection platform (DCP). Many of these remote sensors (for example, those used in the Physical Oceanographic Real-Time System [PORTS®] network) are located at field stations that generate data in real time. These data are then transmitted to the Data Processing and Analysis Subsystem (DPAS) in Silver Spring, Maryland for integration into various CO-OPS products, and those products are transmitted to the public. For operational purposes, each station should have a minimum of two forms of communication– a primary and one or more alternates. The primary communication system is used for all real-time products and should produce the maximum data returns at the lowest cost.

Alternative communication systems must be available in case the primary system fails. Either the primary or alternate communication system should have two-way data communication capabilities to allow for emergency polling, backfilling of data, and/or remote maintenance without interruption of the basic information stream. Ideally, the alternate system should be a two-way system to avoid the interruption of real-time products; however, this is not always practical, especially when cost constraints are considered.

CO-OPS uses several types of systems for primary and secondary data communications. They include geostationary operational environmental satellites (GOES), telephone lines, line-of-sight radios, and Internet protocol (IP) modems. GOES currently serves and will likely continue to serve as our primary method of data retrieval from field stations. The GOES system is a federally funded NOAA satellite and delivers real-time one-way data transmissions from the field to receivers on the ground station at Wallops Island, Virginia. Data are transmitted to two satellites, East and West, with timeslots on 17 channels. These channel-timeslots are called GOES IDs. After transmission to the Wallops Island ground station, these data are then disseminated to CO-OPS and other users. The main concern with this system is the availability of new GOES ID allotments on the appropriate satellite, which is required in order to maintain the current rate of growth.

Over the last five years, CO-OPS has acquired GOES IDs at a slightly faster rate than the growing needs. Even though we do not know whether or not this growth rate will continue, we must anticipate future requirements and constraints. We must account for the addition of new sensors that transmit larger data messages (such as acoustic Doppler current profilers or ADCPs), as well as for annual growth of the existing system suite. It is difficult to predict our needs even three to four years from now.

To add to the uncertainty of future requirements, it is also unclear how much the Integrated Ocean Observing System (IOOS) will use the GOES satellites for data transmission, and whether NOAA will provide universities and other researchers with GOES IDs for their data collection. The National Environmental Satellite Data and Information Service/Data Collection System (NESDIS/DCS), is the NOAA line office responsible for assigning GOES IDs. Competition from other agencies for GOES IDs may make it more difficult for us to acquire new IDs in the future.

In anticipation of a growing need for GOES ID allotments, CO-OPS recently submitted a memorandum to NESDIS/DCS (see Appendix A) outlining the types of data transmittal necessary to maintain our anticipated system growth, the requirement for longer data transmittals, and the need to convert more coastal stations into reporting every six minutes. This memorandum requested additional GOES IDs to meet the requirement for 300+ NWLON (National Water Level Observation Network) stations (the number needed to complete the NWLON) transmitting at six-minute intervals by 2012. Additionally, we requested several 1200 baud rate data platform IDs for sensors with larger data messages (particularly ADCP) so that data could be effectively transmitted.

After reviewing our request, NESDIS/DCS has indicated that they will probably be able to meet these requirements either when they make anticipated changes to the ground system or when the GOES R satellite is launched in 2012 (see Section 2.2). We will be required to properly justify the need for additional GOES IDs capable of six-minute transmissions. It is unclear at the present time when NESDIS will make these changes and/or whether budget restraints will alter their plans. In view of this uncertainty and in light of the fact that more appropriate systems exist for certain applications, we must consider an alternative method of data retrieval to ensure readiness for future requirements.

1.3 Organization of this Document

This document is organized in six sections:

Section 1.0 outlines the purpose of the document, as well as an overview of the existing data communication system, and the impetus for preparation of this document.

Section 2.0 explains the current and future capabilities of GOES satellites in data communications.

Section 3.0 discusses current and future land-based data communication systems, including telephone lines, line-of-sight radios, and Internet Protocol (IP) modems.

Section 4.0 describes the six specific requirements that data communications systems must meet.

Section 5.0 describes how data communications systems will be used in the next generation, and discusses how each one meets the current and future requirements outlined in Section 4.0.

Section 6.0 presents conclusions and recommendations of the future direction of data communication systems within CO-OPS.

2.0 Current and Future GOES Capabilities

2.1 GOES.

The GOES system consists of (a minimum of) two geostationary satellites, each covering 1/3 of the globe. One satellite covers the Atlantic Ocean and Eastern U.S. and the other covers the Pacific Ocean and Western U.S. Geostationary satellites do not move relative to an observer on the Earth and are always in view of the same ground stations and field stations; therefore, real-time data can be obtained in any area covered by one of these satellites. GOES can be used anywhere that has a clear view of the satellite and sufficient power available (Figure 1).

Figure 1

Because GOES covers only 2/3 of the globe, it is not a 'global' system—platforms in its footprint are always covered, but platforms on the other 1/3 of the earth's surface are never covered (Figure 2). Stations (such as Guam) that are outside or on the edge of the GOES footprint cannot use this system for data transmission; therefore, an alternative method of data transmittal must be found. Another constraint of the GOES system is that it is only capable of limited two-way data transmission. Complete two-way communication links are critical when high data sampling is required (such as when monitoring a tsunami), as well as during system restarts, upgrades, or backfilling of missed transmissions.

Since GOES is a federally funded NOAA satellite, we do not incur a monthly charge for the use of this system. Generally, GOES is used for all CO-OPS water level stations, with a telephone

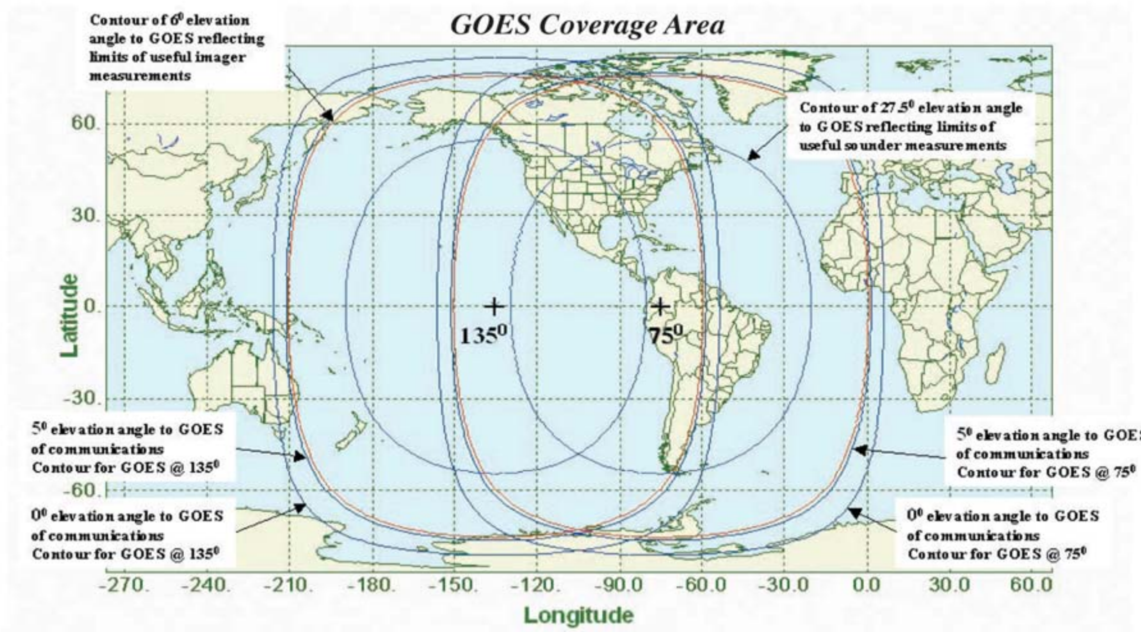

Figure 2

line as a backup (where available). If GOES is available, it should be the primary line of communication to that station because it is the sturdiest system available, and incurs only a minimal operating cost. GOES should be coupled with an alternate (backup) system that has two-way data communication available so communications with this system may be initiated if GOES is unavailable.

CO-OPS has significantly increased the use of the GOES satellite over the last 20 years. The number of IDs in use on the Eastern satellite has increased 88% over the last 7 years, from 141 to 266. Even more significant than the number of IDs being used is the fact that very frequent transmissions of data are required on these channels in order to update our products in real time. In 1998, 138 of the 141 IDs being used were only transmitting once every three hours (Figure 3). Over the next few years, CO-OPS requirements changed, and we increased this frequency to once an hour. We are currently updating stations to transmit data once every six minutes. Six-minute IDs transmit more frequently but for a shorter period of time; however they still require more of the GOES resources than our one hour IDs. Many of our six-minute IDs have a five-second transmission window. This means that every hour we are using 50 seconds (10 5-second transmissions) in a channel as opposed to the 30 seconds we are allotted for our one hour IDs.

This new requirement for six-minute transmissions (rather than less frequent transmissions) is slightly problematic for NESDIS because it requires allocation of GOES IDs with a six-minute transmission frequency for all our stations. In addition to our increase in requirements, other agencies using the GOES satellites for data transmittal have now requested similar six-minute transmission availability. Collectively this presents a challenge for NESDIS to supply GOES IDs with a significantly shorter transmission frequency. NESDIS has stated that we must present a ‘strong justification’ for the need of this capability in order to receive any additional six-minute IDs. However, NESDIS has also indicated that if they receive this justification, we should receive an additional 6-minute channel (66 6-minute IDs) on the Western satellite in 2006 without difficulty.

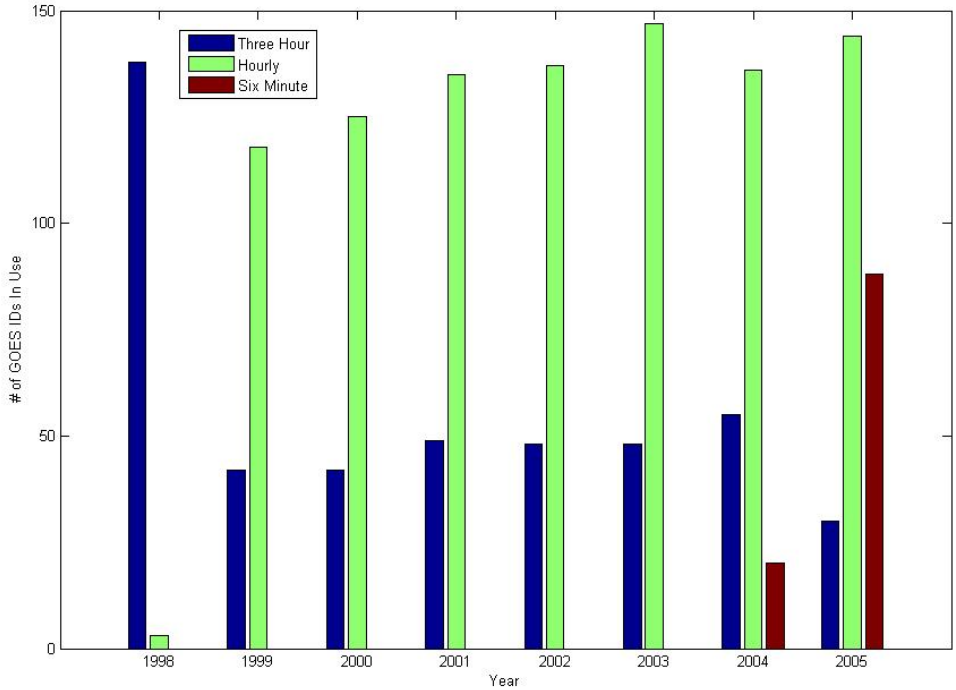

Figure 3

2.2 New GOES Capabilities and GOES-R

NESDIS plans to increase the number of frequency allocations (or GOES IDs) currently available by upgrading the Wallops Island receiving station. This will be accomplished by decreasing the frequency buffer between IDs, which will approximately double the number of IDs available. Advances in technology since the existing system was originally developed allow for more precise usage of the exact assigned frequencies; therefore, a smaller frequency buffer between IDs is now required than when the system was first developed. If this plan becomes a reality, obtaining more GOES IDs may not be a problem; however, the lack of a definitive timeframe for implementation makes planning difficult.

In addition to updating the Wallops Island receiving station, advancements have been made in establishing a backup GOES DCS receiving station. The Wallops Island receiving station was recognized as a single point of failure to the GOES system. In 2000, a backup system receiving station was opened at Goddard Space Flight Center in Greenbelt, Maryland. This station is operated in backup mode with personnel from the Wallops facility being deployed to the site in the event that a foreseeable emergency (such as a hurricane) threatens Wallops. Due to the proximate location of the Goddard Space Flight Center to the Wallops Island facility, the USGS is building an additional backup facility in Sioux Falls, South Dakota. When this is complete, a total of three receiving stations will be able to access and rebroadcast data received from the GOES satellite.

The new GOES-R satellite, set to be launched in 2012, will offer significant advances in the data transfer capabilities of the system. Currently, each GOES satellite has 200 data transfer channels available. The GOES-R satellite doubles this capacity with 400 channels available, which allows 1000 hourly tide station transmissions as a minimum and 5000 6-minute tide station transmissions as the ideal. The first GOES-R satellite will be launched in 2012 to replace the current Western satellite. Although this document only attempts to predict communication needs prior to the GOES-R launch, consideration of these future advances are important to ensure that CO-OPS can still fully utilize these resources.

2.3 DOMSAT

The United States is covered by at least two GOES satellites—one for the Atlantic Ocean and Eastern U.S. and one for the Pacific Ocean and Western US. While this configuration works well for coverage, East Coast receivers generally cannot receive data from the Western satellite and vice versa, except for a few transmitters located at the edge of satellite footprints. The DOMSAT (domestic satellite) sends data between the two GOES satellites. Once GOES data are received by NESDIS at the respective ground station, the messages are rebroadcast in the same format to the DOMSAT satellite, which is located in the central US with full view of the continental US. The DOMSAT satellite can retransmit to any DOMSAT receiver in the continental US, which is very important for real-time data access and backup systems. CO-OPS has DOMSAT receivers at the Seattle and Chesapeake facilities and has access to a receiver owned by the National Weather Service (NWS) in Silver Spring. We can receive data from either the Eastern or Western satellite.

DOMSAT charges are paid through the STIWG by the larger users, such as the USGS, USACE, and NOS, using the administrative support of the Office of the Federal Coordinator for Meteorology (OFCM). Presently, DOMSAT is prepaid through 31 October 2008. At the May 2006 STIWG meeting, several participants felt that DOMSAT could be replaced by the Low Rate Information Transmission (LRIT) system aboard GOES. The digital LRIT is an international standard for data transmission that was developed by the Coordination Group for Meteorological Satellites (CGMS) in response to the recommendation for digital meteorological satellite broadcasts. The CGMS Global Specification provides the standard that is supported by all operational geostationary meteorological satellites to be flown by the U.S., Europe, Japan, China, and Russia. NOAA and other world meteorological agencies have developed subsequent system specifications, designs, and implementations of their specific LRIT systems. More information about LRIT is available at http://noaasis.noaa.gov/LRIT/docs&links.html.

3.0 Current Land Based Communication Capabilities

3.1 Telephone Lines

CO-OPS presently uses telephone lines (also known as the public switched telephone network or PSTN) to call a station's DCP through a modem to backfill data records when transmissions from the GOES satellites are not properly received. All DCPs have a standard modem built in to the system, although not all have telephone line access. Generally, the telephone is the secondary communication system for a station. In this case, the data acquisition system (DAS) calls into the DCP and retrieves data as needed when large data gaps exist. The telephone is the secondary system used on most water level stations, with GOES as the primary system. Occasionally the telephone is the primary system for data collection, such as at many Great Lakes stations, although this system is being phased out as DCP upgrades occur.

The PSTN has many advantages, as it is very stable compared to other forms of communication. Because telephone access is a two-way system, it can also be used for remote maintenance to a station. However, because the PSTN is on the ground, it is susceptible to local weather events such as hurricanes or other outages. Additionally, a PSTN connection is impossible at some sites (e.g. unserviced isolated areas and buoys).

3.2 Line-of-Sight Radios

Line-of-site radios are used in pairs: CO-OPS supplies both the data source and data receive transceivers. Line-of-sight radios are used to transfer data between two terrestrial points that do not have another viable or desirable method of data transfer. One transceiver is generally located at the sensor or DCP, the other at the DCP or DAS respectively (e.g. the aid-to-navigation [ATON] buoys transmit current profiles to DCPs). Line-of-sight radios can transmit the full current profile to the DCP, where it can then be accessed by another communication option (in this case, an IP modem).

We use line-of-sight radios (transmitters and receivers) where telephone access is not available to each station but can be made to a central location, or where a backup system is needed. For example, PORTS® data are usually transmitted to a central location (DCP) where the data can then be collected and transferred back to the DAS. Radios are used to transmit data from multiple stations in proximity to this central location so that data can be collected together. Line-of-sight radios are currently used in ATONs, as well as in the following PORTS® or water level monitoring systems: Narragansett Bay, Delaware Bay, Houston/Galveston, Tampa Bay, and Los Angeles/Long Beach.

Line-of-sight radios are a good option when data must be gathered from multiple remote stations and forwarded to a central area in order to be further transmitted. Due to the curvature of the earth and problems with frequency interruption, line-of-sight radios cannot be used for long distance data transmittal (typical range 20 to 30 km). They require a base station that can be accessed via another type of communications system (GOES, telephone, or another 'long distance' method of communication), but have no monthly fee except for maintenance and the cost of the base station. Also, since line-of-sight radios were among the first data communications systems used to provide real-time (six-minute) data telemetry, the older stations are more likely to be equipped with them than the newer stations, which are more likely to have IP modems.

One of the biggest problems with line-of-site is the requirement to find a location and maintain a base receiving station that has an environmental enclosure, receiving radio, antenna (and maybe an antenna tower), data interface, an energy source, and a data connection from the base station to CO-OPS headquarters. Another issue is that the communication equipment occasionally fails to function properly due to corrupted commands, lightning strikes, unhandled data overloads, etc. Some line-of-sight radios handle these problems better than others because of design, but most must have an external automated reset to keep them operating reliably.

CO-OPS uses two major categories of line-of-sight radios: a narrow band frequency specifically allocated to NOS, and wide frequency bands available to many users. Our traditional line-of-site allocated frequency is in the 406 to 420 megahertz (MHz) band, with most at our coastal allocation of 410.45 MHz. Most allocations within this band have been reduced to a 12.5 kilohertz (kHz) bandwidth (which can support a 9600 baud data rate), with a strong possibility of being further reduced to 6.25 kHz. We have used 1200 to 9600 baud rates depending on the radio, distance, and the time in history. At 4800 baud, it takes about one second to send a full binary current profiler record. Narrow band allocated frequency radio (typically five watt units) allows the user to have dedicated frequency channels with no interference, and the allowed transmission power is limited by the allocation license as well as the power source.

There are two wide frequency bands open for general use. No allocation is required; however, the user must stay within the limits of use. One band is around 900 MHz and the other around 2400 MHz. These bands, 25 and 83 MHz wide respectively, each contain many sub-bands capable of 100 kBaud data rates. Transmission power is limited to one watt, and the FCC sets restrictions on the gain of the antenna. The radios operating within these bands use frequency hopping—periodically the radio jumps to another frequency sub-band (both radios know the jump sequence). High end radios have achieved long-term 40 kBaud data rates at 15 miles; however, because of the inherent properties of the method and the power limitations, they are more susceptible to interference and signal reflections.

There are some lower frequency communication options below 170 MHz, whose main advantage is longer over-the-horizon communication range. The disadvantages of the lower frequency include higher transmitter power, lower data throughput, larger antennas, and almost non-existent frequency allocations.

3.3 Internet Protocol (IP) Modems

Operationally, IP modems are similar to line-of-sight radios. IP modem data rates are in the 10 to 20 kBaud range; however, they use the cellular network as a base station. The remote site can either initiate or answer the connection. Unfortunately some cell phone towers do not have the proper firmware upgrades to handle this feature. The system is plagued with the “Are you there?” syndrome. There are sites that have yielded a 99% data return, and others that were good and then became “spotty”. Hopefully the system will improve as commercial cellular coverage and capabilities improve.

IP modems are generally used in PORTS® stations as the primary communication with a telephone as the first alternate system. If six-minute GOES transmissions are available at a station, GOES is the station’s primary method of communication and the IP modem is used as a first alternate, with the telephone as the second alternate. IP modems connect directly to the DCP at a station, and they can be used for two-way communication from a remote location, allowing data to be polled or remote maintenance to be conducted. When a system is polled over an IP modem, the DAS initiates a connection with the DCP through the IP and uses the *Login* prompt to request the most recent sample to be transmitted back to it. If remote maintenance is being conducted, the connection can be initiated by a user through X-term software that is designed to give the user access to DCP controls.

Cellular network data transfer privileges cost from $70 to $80 per month for IP modems; however, there are no base station costs, as data are transmitted directly from the site to Silver Spring via the cellular/Internet. IP modems are limited to areas with good cellular coverage to ensure good data quality, so they typically cannot be used in isolated areas. IP modems are currently used in the Chesapeake Bay, Delaware Bay, and New York.

A disadvantage to cellular technology is that it can fail during hurricanes or other events that disrupt land-based systems.

4.0 Current and Future System Requirements

Before considering the next generation of data communications options, CO-OPS must first determine both the current and future requirements. This is difficult, as even now our requirements are increasing with the number of existing stations. Additionally, recent natural disasters such as the Indian Ocean tsunami and Hurricane Katrina have made certain capabilities a priority—for example, two-way communications or the ability to poll data more frequently than every six minutes during such events. At a minimum, a communications system must meet the following requirements before resources are expended to develop a technology for integration into the existing CO-OPS framework.

- Reliable real-time data (every six minutes)
- Company/system stability
- Acceptable cost
- Ability to expand usage
- System versatility
- Two-way communication capability

The following paragraphs provide a more in-depth look at each requirement.

4.1 Reliable Real-Time Data (every six minutes)

Any communications system selected must reliably return data every six minutes in order to update our real-time products. Many systems can provide global coverage in "near-real time"; however, this does not ensure a consistent six-minute update, which is critical to the reliability and quality of our products, as well as ensuring standardization in acquiring data. Although some applications may not always require a six-minute update, it is easier to use a system that is capable of this in an application where it is not needed than to maintain a separate system that could never be used for operational products.

4.2 Company/System Stability

Before investing resources in a system, we must have confidence that both the company and the system will still be in place years into the future. The point of planning and investing resources is for the future–not for short-term solutions. Although it is hard to "measure" and to determine exactly how stable a company is, the customer base and rate of growth are indicators that provide a feeling of stability. Additionally, evaluating the lifetime of the existing network and replacement planning can provide an indication of how long the infrastructure will be maintained.

Company stability is particularly important, considering the past financial difficulties of many of the satellite communications systems. Many of these companies (GlobalStar, ORBCOMM) have been in Chapter 11 bankruptcy protection. The financially troubled Iridium LLC was unable to recover from extensive start-up costs and was acquired by Iridium Satellite LLC. The newly-formed company was rescued by the U.S. Department of Defense's (DOD) substantial investment; similarly, many other small satellite communication systems have also been consolidated and/or acquired by larger companies.

System reliability can be evaluated by polling existing users to determine the system's outage frequency and the corporate response to each occurrence. The experiences of other users, particularly those in the oceanographic community, should be considered before resources are expended to develop a new communications system.

4.3 Acceptable Cost

NOAA provides data transmission via GOES, and polling data with a dial-up connection only incurs the cost of the phone call. This makes our current GOES/telephone system competitive in any area where one or both of these capabilities are available. If another system is needed, the recurring cost of data transmission must be carefully evaluated before deciding which system to use. Some systems base the airtime cost on actual data transmitted, while others calculate the cost based on the amount of time used, generally with a minimum charge. Depending on the pricing method, transmitting every six minutes can add up very quickly; therefore, careful planning is important to determine which system to use for a particular application. Costs within this report are based on water level and ATON ADCP (acoustic Doppler current profiler) transmissions of 32 and 210 bytes every 6 minutes respectively.

4.4 Ability to expand usage

The main concern in using the GOES system for data collection is that it is unclear if the system will be able to meet our future growth requirements. Requirements for large data sets have been growing at a rate of six percent annually, and so far we have access to sufficient GOES IDs to maintain this growth. However, with NOAA and so many other government agencies depending on GOES, it is unlikely that an adequate supply of GOES IDs will continue indefinitely, especially with the expansion of the IOOS, which will cause more demand for satellite access. Investing in a secondary satellite system will allow us to continue the current rate of growth with confidence, but only if the secondary system has adequate room for expansion.

4.5 System Versatility

In order for a system to be used throughout CO-OPS, it must be easily integrated into many different applications. With new systems emerging, such as current profilers mounted on ATON buoys, data do not necessarily go directly into a DCP to be transmitted (in this case, data are first sent to a MaxStream line-of-sight radio, which then transmits the data to a DCP). The limited power available precludes direct telemetry via GOES (due to power constraints), so data are transmitted to a shore station through a more power-efficient medium (line-of-sight radio). The shore station generally has ample alternating current (AC) available.

There is also a critical need for a back-up telemetry system in the event of a primary system failure. The main advantage of using satellite technology over land-based systems is that satellites are not susceptible to the same weather events as land-based systems. For example, if a hurricane hits an area and the PSTN goes down, the cellular network would likely be disrupted as well. If a weather event that blocks satellite transmissions occurs, then a land-based system may be the most feasible candidate for providing backup capabilities. Assuming that the weather event does not disrupt land-based instruments (such as antennas), the land-based system should back up a satellite system, and vice versa.

4.6 Two-way communication capability

Two-way communication is becoming increasingly important for day-to-day maintenance of remote systems. Systems located in remote areas require that we have the ability to access the system without physically being on site to conduct maintenance. Examples of maintenance issues that could be conducted remotely include system restarts, software upgrades, or backfilling missed data transmissions. Remote access saves both financial and personnel resources from frequent site visits that may not be needed. Although IP modems and telephone lines allow this type of access, these systems are often not available in extremely remote locations. Indeed, these remote locations are where this type of access would be the most beneficial for CO-OPS use. The communications option available through GOES does not allow the level of two-way communication necessary for maintenance to be conducted; therefore, this capability should be incorporated into new satellite systems that are considered for the future.

5.0 Next Generation of Data Communication Possibilities

The next generation of data communication will likely feature a combination of mobile satellite systems (MSS), cellular coastal networks, and traditional terrestrial systems. Traditional terrestrial systems, such as telephone lines, will likely play a role in future communications systems. Cellular networks for data transmission are not yet well developed; however, their infrastructure is still dependent upon PSTN to provide service to the coastal community. MSS will likely dominate the next generation of data communications with its three types of satellites, which include geostationary earth orbit (GEO), mid-altitude earth (MEO) orbit, and low earth orbit (LEO). The MSS are categorized by their orbit altitude as follows:

GEO Approximate Altitude: 35000 kilometers (21000 miles)
MEO Approximate Altitude: 10000 kilometers (6000 miles)
LEO Approximate Altitude: <1000 kilometers (<600 miles)

The GOES satellite is a GEO satellite, which means that the position of the satellite does not change relative to the Earth because it is orbiting the earth at the same angular speed that the earth is rotating on its axis. The footprint of the satellite covers 1/3 of the Earth's surface and always has the same view of the transmitting and the receiving stations.

However, LEO satellites do not share this luxury—individual satellites have a very small footprint and may not always have view of a ground station. Real-time data collection requires that these data be transmitted even if a LEO satellite does not have sight of a ground station. Three major methods of data transmittal exist for LEO satellites: store-and-forward, bent-arm (sometimes called bent-pipe), and intersatellite links.

Store-and-forward mode requires that a station send data to a passing satellite when the satellite is overhead. The satellite must then store the data until it passes over a receiving ground station, at which point it downlinks the data, which then become available. Depending on the location of the transmitting and receiving stations, a considerable amount of time could elapse; therefore this type of system would not work well for real-time data transmittal.

The bent-arm system transmits data in real time by receiving data from a transmitting station and immediately sending the data back to a receiving station. However, in order for a bent-arm data transmittal system to work, the satellite must have both the initiating station and satellite receiving ground station within its footprint at the same time. For this reason, systems often use the bent-arm method in conjunction with a store-and-forward system to cover areas that do not have a ground station within the same satellite footprint as the transmitting station.

The intersatellite links system is the only method that can be used for real-time data transmittal on a regular, continuous basis (for example, once every six minutes). In an intersatellite linked system, data are transmitted from an initiating station to a satellite, and can be transmitted from that satellite to other satellites in the constellation. This continues until the data reach one that is in view of a receiving ground station, at which point the data can be downlinked. This allows for real-time data transmittal when at least one of the satellites is within view of an initiating station and at least one of the satellites is within view of a receiving ground station.

Several companies employ MSS technology that provides data communication for a variety of consumers. The following subsections examine these next-generation systems, their advantages and disadvantages relative to the six current and future requirements established in Section 4.0. These systems include:

- Inmarsat
- Iridium
- ORBCOMM
- Globalstar
- ARGOS

5.1 Inmarsat

The Inmarsat satellite communications network is primarily used for complete communications solutions for the maritime and aeronautical industries. The network consists of overlapping GEO satellites that provide voice, fax and data services globally except at the poles. These satellites connect to 29 ground stations to provide emergency communications and tracking for ships. Inmarsat offers an array of services, depending on the types, speed, and location of services needed.

Fleet Services. Inmarsat's premier maritime system is the Fleet Services package, which provides complete Internet, phone, fax and e-mail to ships at sea. There are three levels of Fleet service, although all of them are likely more than required. F77 provides global 128 kbits/s (kilobits per second) voice, fax and data services that charge by the amount of data sent rather than time online, so it is possible to keep this system always online. This system provides the equivalent of local area (LAN) or private network access. Both F55 and F33 are similar systems, operating at 64 kbits/s (only in spotbeams) and 9.6 kbits/s respectively.

Fleet 33 is the lowest data rate Fleet system available and, of the three, the most applicable to our needs. However, this system operates only in the Inmarsat spotbeams (Figure 4); it is not available globally, but seems to cover most areas that we require. Dial-up data capabilities operate at 9600 baud within the spotbeams. Within the Fleet system, we would use the Mobile Packet Data Service (MPDS), which allows the transmittal of frequent, non-urgent packets of data. Due to the "always on" capabilities, the system works like a digital subscriber line (DSL) with real-time transmittal abilities over a 64 kbits/s download and 28 kbits/s upload channel.

This service also includes voice and fax. The equipment for this service (referred to as 'Below Deck Equipment') is larger and requires much more power than our current systems. The modem is 310 x 180 x 80 millimeters (mm) and weighs 1.5 kilograms (kg). The antenna for this system has a 0.4 meter diameter and weighs 8 kg. The power input is between 19 and 32 volts, hence this equipment is considerably larger and requires a much higher voltage than we currently employ.

The Fleet 33 system is typically used as a shipboard system, so it has higher data transfer rates than our application requires. For this reason, costs for data transferred over the Fleet 33 system are in ½ Mbit increments ($1.78 each). With this minimum charge per transmittal, this would total an astronomical $12,816.00 per 30-day month.

Inmarsat C is a message-based data communications system, transmitting data bursts at 600 bits per second (bps). This system allows data messaging from field stations on request or at prearranged intervals. Although not a direct connection, two-way messaging is also available for a single station or for a prearranged group of stations. This system is available in all four of the major Inmarsat coverage regions shown within the four circles in Figure 4. The blue areas represent the regions covered by spotbeams.

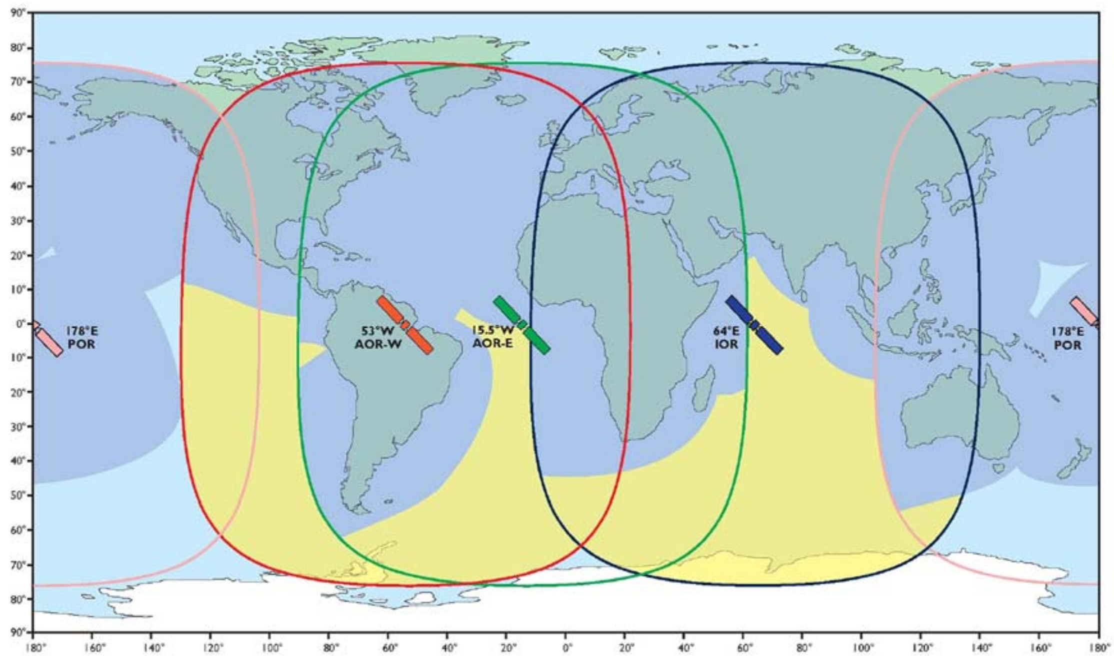

Figure 4

Pricing for Inmarsat C is based on the size of the message sent. The following provides the cost of 1-32 bytes:

Message Size	Cost
1 to 8 bytes	$0.06 per transmittal
9 to 20 bytes	$0.10 per transmittal
20 to 32 bytes	$0.15 per transmittal

For messages larger than 32 bytes, multiple messages must be sent in succession. For example, to achieve the 210 bytes of data every 6 minutes (required for ADCP transmittal), 7 consecutive 32-byte messages must be sent. This results in a cost of $1.05 every six minutes for this type of transmittal. While this system may work for stations transmitting less than 32 bytes every 6 minutes, larger data messages are extremely expensive using the Inmarsat system.

Inmarsat D+ is a very low data rate system that is used primarily to transmit GPS positions. It is two-way capable, with 9 bps to the field station, with a data latency of 3 minutes. For the field station the rate increases up to an 80 bit message at 10 bps with a latency of 30 seconds. Again, this system is not practical for CO-OPS applications because of delay and low data rate. .

Inmarsat M and mini-M are global 2.4 kbit/s data service. Inmarsat mini-M is a similar service, advertised for up to 9600 baud with compression, but it is only available within spotbeams.

These systems are primarily phone networks, so it may be unwise for CO-OPS to begin using them for data transmission. Since our application would be a minority user of this system, it may or may not be well supported.

Inmarsat B is made exclusively for ships. Their terminal is even much larger than the Fleet systems and is not practical for CO-OPS applications.

Inmarsat A is a two-way, direct dial that supports data rates from 9.6 kbit/s to 64 kbit/s and is used mainly for voice, fax, telex, e-mail and data. The system is still available; however, because it is an older analog system, it is being phased out.

Table 1. Inmarsat Fleet Services		
System Requirement	**Advantages**	**Disadvantages**
Reliable real-time data	Fleet 33 offers the equivalent of DSL within spotbeams and Inmarsat C offers messaging in real-time.	
Company stability	Major shipping companies use Inmarsat for shore communications such as telephone and e-mail. It is also used by other industries, including aeronautical, so it has a broad user network. Currently expanding number of satellites and services available.	Most services are made for commercial vessels, and therefore include many more services than we need.
Reasonable cost	Monthly Costs: Fleet 33 WL: $12,816.00 Fleet 33 ATON: $12,816.00 Inmarsat C WL: $1,080.00 Inmarsat C ATON: $7,560.00	Fleet 33 has a minimum per message charge of ½ Mbit. Inmarsat C has a maximum per message size of 32 bytes, although multiple messages can be sent in succession.
Ability to expand usage	For-profit companies will upgrade system rather than let it reach capacity if their technology is being that heavily used.	CO-OPS application is a minority in the customer base – new applications will likely be made for vessel services instead of fixed stations.
System versatility	Many different types of service available. These services cannot be used together, as each requires different hardware.	Most services are made for commercial maritime and aeronautical vessels, and therefore include many more services than we need.
Two-way communication capability	Fleet 33 offers complete two-way communication and Inmarsat C offers two-way messaging.	

5.2 Iridium Satellite, LLC

The Iridium system consists of 66 satellites with 13 spares in orbit. To this date, only one of the satellites has failed. The major advantages of the Iridium system are its global scale (most other satellite systems do not cover the poles in real time, if at all) and real-time communications (this is the only LEO system with intersatellite link capabilities). Since this technology uses interlinking satellite communications, it is not necessary for the satellite receiving the data to be in view of a ground station to transmit data to the gateway*. Iridium also provides better coverage than other LEO systems because the Iridium constellation covers the two poles as well as it does the rest of Earth (Figure 5). Most other LEO satellite constellations do not cover the poles at all, or their coverage is very limited because the satellites do not pass by the poles as frequently as they do other parts of the globe.

Figure 5

The Iridium system has diverse support from several government agencies, including the DOD, NOAA, and the National Data Buoy Center (NDBC) Deep-Ocean Assessment and Reporting of Tsunamis (DART) buoys. DOD uses Iridium on a very large scale and has heavily invested because of the global, two-way, real-time data access. DOD now has its own dedicated gateway in Hawaii (separate from the commercial gateway in Arizona). NOAA/NDBC and the NWS procured 160 units for its Coastal Marine Automated Network (CMAN) and also use Iridium for ship and aircraft email. Ocean US, an interagency ocean observation organization, has supported Iridium's development within the oceanographic community, and it appears that Iridium is quickly becoming the premier LEO satellite communications system for the oceanographic community. Others utilizing Iridium include Woods Hole Oceanographic Institute and Axys Technologies, Inc.

* Iridium uses the term "gateway" to refer to the ground station through which a satellite signal containing the user's ID followed by the data transmission is received. The terms gateway and ground station are interchangeable.

Non-DOD government agencies can purchase airtime via flat-rate unlimited usage SIM (subscriber identity module) cards for $289 per month under an interagency contract. This is an alternative to commercial cards; however, these flat-rate cards are not available to non-government users. This is discussed in more detail later in this section.

Overall, Iridium has experienced a 22% growth in new subscribers from the third quarter of 2004 through the third quarter of 2005, and the revenue for the nine-month period ending September 2005 was up 24% over the nine months ending September 2004. In fiscal year (FY) 2004 alone, Iridium sold 3800 modems.

Even without upgrades, Iridium satellites will be functioning without replacement until at least 2014. Plans are already underway to begin replacing these satellites by 2012. DOD, like the oceanographic community, requires global, two-way, real-time access. Since Iridium may be the only system that can reliably provide this access, it is unlikely that DOD will stop using Iridium anytime soon; therefore, the system and company appear to be stable.

The following paragraphs provide an overview of the various options available with the Iridium system, as well as costs associated with those options.

Short Burst Data (SBD). SBD is Iridium's packaged data service, which is similar to a GOES message, except it is delivered via an email or IP address. This address is established when the equipment is purchased and is associated with the modem (not SIM card) being used. Under the DOD network, SBD messages can be sent to either multiple email addresses or a single IP address. CO-OPS prefers to use multiple IP addresses to ensure that there is not a single failure point within the system. Although this feature may be currently available on a case-by-case basis, it is scheduled to become standard throughout all DOD Iridium systems by 2007. A single SBD message can be up to 1960 bytes (binary or ASCII data can be transmitted) and does not require a complete connection to occur. This saves power at the remote transmitter, reduces data latency, and makes more efficient use of the entire Iridium system. Once initiated, a message is transmitted to the Iridium gateway, where it is immediately forwarded onto the associated IP or email address. Unlike other burst data capabilities with some LEO systems, this service can be used for real-time data transmission because of Iridium's hand-off capability. In any operational usage of SBD, the data message is transmitted to two IP addresses (one as a primary and the other as a backup). The Iridium gateway does not save the message after a receipt confirmation has been transmitted to the associated IP or email address. Even though SBD has a 99% throughput rate, CO-OPS may wish to avoid depending on email so that incoming data will not be interrupted by such things as routine e-mail server maintenance.

OSTEP is pursuing the use of SBD for ATON systems in areas where the buoy is far away from the shore station, as a replacement for the MaxStream line-of-sight radios and shore station systems. It is hoped that this system will return a better data percentage return for ATONS, as well as eliminating the necessity of a shore station. Once implemented, the Iridium modem will connect directly to the end of the Nortek current profiler and data will be transmitted through the Iridium system to an IP address at the Silver Spring facility, where the data can be decoded and placed onto the DAS.

The difference in price between commercial SIM cards and the flat rate, unlimited usage SIM cards available from DOD was compared based on estimated usage for the Iridium/ATON system integration. Due to the large amount of data sent from the ATON systems, it is more cost effective to procure the DOD flat rate SIM cards than the commercial cards. Commercial cards cost $0.80 per 1000 bytes with a 30-byte minimum, so the service charge per month for 210 bytes of data is 0.315 per message, or $2268.00 per 30-day month. The DOD flat rate SIM cards have a $168.78 recurring monthly charge for usage, plus $112.71 per month for usage of the exclusive DOD gateway. This totals $281.49 per month for unlimited use of all short burst dial-up data connections.

Dial-in Data. A dial-in data connection via Iridium is a new possibility for remote maintenance communications with an Xpert DCP system in the field as well as data collection in emergency situations. When using dial-in data, a complete connection that allows the user to interact with the station that has been called is initiated. From the user's perspective, a dial-in Iridium connection is similar to an IP or telephone connection. When connected to an Xpert DCP system, the user can access the system through the typical *Login:* prompt that is used to access these systems.

The dial-in capability is particularly useful in conjunction with the new Command Line OS (operating system) that Sutron has recently released. Using a dial-in connection with the command line features, remote maintenance may be conducted through an Iridium modem. Although further testing is needed to determine the robustness of this connection, this type of connection would have major implications for routine, remote maintenance in areas where IP and telephone connections are not possible. Recent examples of stations in Guam and Tangier Island have demonstrated what a remarkable feature this would be.

For an irregular dial-in application such as remote maintenance, the most cost effective plan for transmitting data on a limited basis is through a commercial SIM card on a corporate data plan. Commercial cards cost ~$30 per month for service charges, plus any incurred airtime charges ($1 per minute airtime charge for calls initiated on this modem). Although, no Iridium airtime charges are incurred for a call made from anywhere on the PSTN to an Iridium modem in the field, a hidden cost exists in the current GSA long distance plan when initiating a call on the PSTN. All Iridium numbers are considered to be an international phone call, and a charge of $7.20 per minute with a one-minute minimum is incurred from the GSA long distance plan that both the Chesapeake and Silver Spring facilities are currently using. There may be a way to bypass the GSA Iridium charges by using an Iridium modem in the office to dial another Iridium modem in the field, with a combined cost of $2.00 per minute ($1 per minute Iridium airtime charges per modem). While this option may not be cost effective for real time data collection, it may prove to be an excellent option for remote maintenance with stations in areas without telephone or IP coverage, which would ordinarily require personnel to travel to the station to perform the same function.

Direct Internet Connection. The direct data connection option for Iridium uses the modem to connect directly to an ISP (Internet service provider) to obtain full Internet access. This option would allow us to dial into the CO-OPS network and obtain complete Internet access from it (just like dialing in to use the office Internet access from a hotel room). This option requires a PC (not a Macintosh) for complete Internet access and could be used by the field personnel to ensure that the data connection reaches remote sights where other options are not available.

RUDICS. RUDICS (router-based unrestricted digital internetworking connectivity system) is a relatively new capability for the Iridium system. RUDICS is similar to dial-in data, except, instead of dialing directly to the Iridium modem in the field; the call is processed through a group of dedicated switched modems that are already connected to the Iridium network (Figure 6). This significantly reduces the call initialization time (20-30 seconds with dial-in data), since the call no longer must be connected to the network. Each time a standard dial-in call is initiated, a suite of safeguards (such as checking the SIM card status, checking to verify that the modem IMEI [International Mobile Equipment Identity] number is valid, and establishing a satellite link) are employed. When using the RUDICS system, the modems are already initialized onto the Iridium system; therefore when a call is placed to a field modem, the connection is almost instantaneous. This saves power at the remote transmitter, reduces data latency, and makes more efficient use of the entire Iridium system.

If the Iridium network were ever to be used on a large-scale (such as if **all** water level stations were going to use it as their primary communications line), then RUDICS would be an ideal situation. Other large scale systems (such as DART buoys deployed with Iridium capabilities) are taking advantage of RUDICS' benefits. However, the high initial costs of RUDICS ($25,000 start-up fees in order to be placed into the dedicated network) likely makes it overkill for the level of usage currently needed.

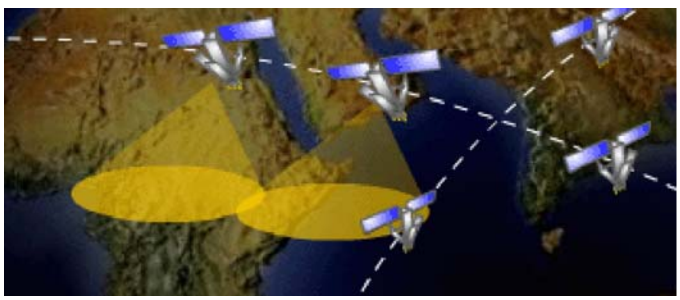

Figure 6

Table 2. Iridium Satellite LLC		
System Requirement	**Advantages**	**Disadvantages**
Reliable real-time data	Only globally available LEO system. Dial-in data or short burst data can be used.	
Company stability	DoD has a large investment in Iridium and has built their own gateway, through which they allow other government agencies purchase airtime. Satellites currently in orbit will last through 2014 (66 + 13 spares) – next generation of Iridium satellites have already been planned and launch dates set. Number of new users is rapidly increasing.	
Reasonable cost	<u>Monthly Costs</u>: Dial in for remote maintenance: $2.00 per minute SBD WL: $281.49 SBD ADCP: $281.49	Costs vary with types of service and service provider (DoD or commercial).
Ability to expand usage	Large percentage of capacity still available. For profit companies will upgrade system rather than let it max out if their technology is being heavily utilized.	
System versatility	Completely global service by using intersatellite link technology. Two systems (SBD and Dial-In data) for use in different geographic areas.	
Two-way communication capability	Available globally for SBD or Dial-In if commercial SIM cards are used.	Dial-in through DoD cards is possible, but requires a lot of 'red tape'.

5.3 ORBCOMM

The ORBCOMM system is a constellation of 30 LEO satellites (35 are in orbit, 30 operational with a license for up to 48, with the last one launched in 1998) and 12 gateway earth stations (GES) that provide global satellite communications except at the poles. The constellation consists of four horizontal planes with poor polar coverage and two polar planes that should cover the poles; however, users have complained that they have been "proven unreliable" (Appendix B).

The ORBCOMM satellite network uses a bent-arm system that receives data from a transmitter on the ground and retransmits to the nearest ground station. From CO-OPS' standpoint, the main "problem" with this system is that, in order for data to be returned in real time, the satellite must be able to view both the transmitting station and a GES to which to transmit. There are 4 GES stations in the U.S. (Washington State, New York State, Georgia, and Arizona), so it is likely that real time data transfer can be achieved in most areas of the 48 contiguous states, although it is not guaranteed. When data are received from a transmitter and there is no ground station within the satellites' footprint, the systems go into a store-and-forward mode, where the data are saved on the satellite until it passes over the next GES and downloaded to that station. This would primarily occur at stations in Hawaii, Alaska, and other isolated areas located far from the mainland. Depending on the amount of time it takes for the satellite to reach another ground station, data would no longer be coming in at real time. Another problem is that there may not be a satellite in view of a given station at any point in time. For example, the closer one gets to the poles the less often a satellite passes over the station to even receive the data. For areas such as Northern Alaska, it could take more than one hour to receive data from a given station because the satellite passes over this area so infrequently.

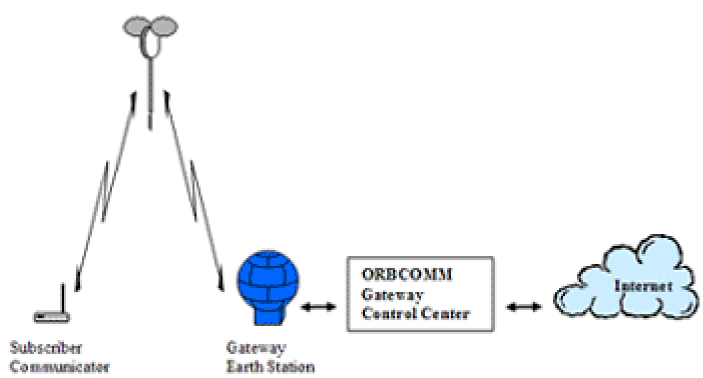

Figure 7

ORBCOMM transmits data in packaged data bursts at 2400 baud. Although these data packages are advertised to be up to 8000 bytes, for reliability and to get the closest to real-time as possible, the bursts should generally be kept under 1000 bytes. In practice, messages larger than 1000 bytes take much longer to return to the end user because a whole message may not have time to up/download while a single satellite is passing over.

ORBCOMM's airtime pricing is based on 'message units', which is the number of bytes divided by 25, if over 107 bytes (otherwise there is a pricing table available). The price per 1000 message units is based on the number of message units sent over a month. Assuming more than 10,000 message units per month, the price would be $19 per 1000 message units. For the transmission of ATON data (210 bytes every six minutes), this would be 60,480 message units per month, which totals $1,149 per station per month. ORBCOMM also has a minimum monthly billing cycle of $2,500.

ORBCOMM has been in Chapter 11 bankruptcy protection since September 2000 because the company has not been able to recover the extremely high startup costs of launching satellites. Although the number of ground stations has been expanding, no satellites have been launched since 1998. The company is scheduled to launch a new satellite in the first quarter of 2006. This satellite will provide the standard narrowband two-way data communications service and will also support the USCG's automatic identification system (AIS), which transmits vessel identification and position.

TABLE 3. ORBCOMM

System Requirement	Advantages	Disadvantages
Reliable real-time data	Areas around continental US should have real-time data without any problem due to proximity of multiple ground stations in region.	Works on a bent-arm system, so real-time data is only available when a satellite is in view of both the ground station and field station at the same time. Areas close to poles not well covered.
Company stability	Number of ground stations has been expanding, new satellite scheduled to be launched in 2006.	In bankruptcy protection since 2000. No new satellites have been launched since 1998.
Reasonable cost	Monthly Costs: WL: $329.69 ATON ADCP: $1,149.00	Minimum monthly billing cycle of $2,500.
Ability to expand usage	For profit companies will upgrade system rather than let it reach capacity if their technology is being that heavily utilized.	
System versatility	Works globally on a store and forward mode, so could be used anywhere in non-real time.	Real-time only works in areas with a ground station located within the same satellite footprint as the field station.
Two-way communication capability	Scheduled to launch a satellite capable of transmitting two way data communication.	Not currently available. Future capabilities designed primarily for USCG's automatic identification system (AIS).

5.4 GlobalStar

The GlobalStar network is a system of 48 LEO satellites that provides voice and data services within approximately 200 miles of major land masses. Communications are established using a bent-arm transmission scheme. Multiple satellites will often communicate with the remote station and ground segment at the same time, to ensure that the data (or voice) is transmitted, even if one of the satellites moves out of range for either system. Globalstar is exclusively a bent-arm system, so isolated areas that are not in the same footprint as a ground station will never receive service. As can be seen from the GlobalStar coverage map (Figure 8), this includes Alaska (fringe area), Hawaii, and the Pacific Islands. While GlobalStar may work well in the continuous 48 states (there are four earth stations in North America), it really will not solve the problem of retrieving data from areas outside of the GOES footprint. The bent-arm system also leaves this network susceptible as a single point of failure because if a ground station fails, then the coverage from the area covered by that station will cease.

GlobalStar provides both burst data[†] and dial-in capabilities. Burst data capabilities use the GlobalStar Simplex Modem or Simplex Transmitter Unit to initiate packet data transmittals from the field on either a time- or event-driven basis at 100 bps. These modems are only capable of one-way data transmittal, so they cannot be polled. Service for the GlobalStar Simplex Modem is limited to North America and Europe, so it is even less global than the coverage map shown in Figure 8. Two-way data communication is also available using the GlobalStar Duplex Modem. This modem provides either direct Internet or dial-in data access to anywhere in the GlobalStar service area at 9600 baud, making this a candidate for a polled data system.

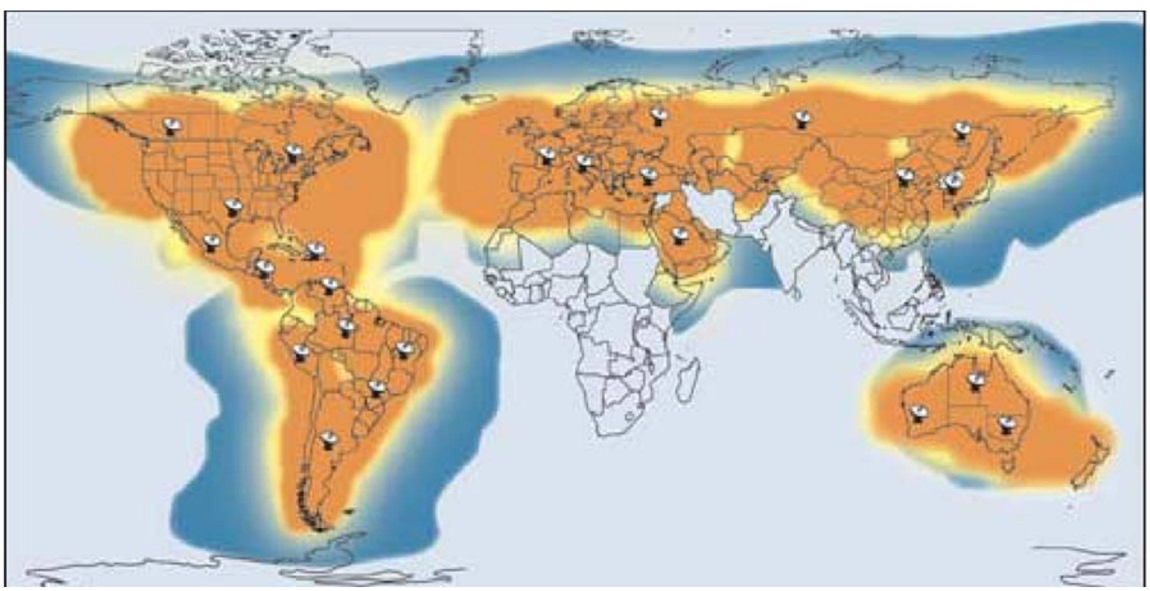

Figure 8

[†] The terms burst data and data burst are interchangeable. Different companies vary on how they use these terms to describe their specific products.

Assuming six-minute data transmittals, the Liberty 48000 plan for $6600 annually ($550 per month) is the best plan for our purposes. This plan allows for 48,000 minutes or 192,000 15-second bundled data transmissions and is the largest data plan available. This would be sufficient for a 30-second transmission every 6 minutes in a 365-day year. Data transmission testing must be conducted to see if this is a reasonable timeframe for data transmissions. Any additional airtime incurred will cost $0.49 per minute or $0.12 per 15 second burst.

Like most of the LEO systems, GlobalStar has undergone several financial setbacks within the last few years. It filed for bankruptcy in February 2002 and has since been acquired by Thermo Capital Partners LLC (Appendix B). However, GlobalStar does plan to launch a replacement system that would include 64 LEO satellites, supplemented by 4 GEO satellites. The lack of ground stations to provide coverage to much of the Earth seems to be the major downfall of the GlobalStar system.

Table 4. GlobalStar

System Requirement	Advantages	Disadvantages
Reliable real-time data	Bent arm system available anywhere within spotbeam of a gateway station. Seems to be primarily a voice system for these areas so this is a requirement.	Areas where this requirement is the most needed are not covered by spotbeams, and thus the system does not have this capability.
Company stability	Seems to have a large user-base. Replacement satellite system including 64 LEO and 4 GEO satellites is being planned.	
Reasonable cost	Monthly Costs: WL: $550.00 ATON ADCP: $550.00	
Ability to expand usage	For profit companies will upgrade system rather than let it max out if their technology is being that heavily utilized.	Seems to be fairly concentrated on voice applications with data as an option.
System versatility	Dial-in and burst data is available.	Alaska, Hawaii, remote Pacific Islands and large portions of ocean not covered.
Two-way communication capability	Available within spotbeams.	Areas where this requirement is the most needed are not covered by spotbeams, and thus does not have this capability.

5.5 ARGOS

The ARGOS system, operated in cooperation with NOAA, NASA, and the French Space Agency (CNES), is attached to NOAA TRIOS weather satellites and now also onboard the Japanese ADEOS-II and European METOP satellites. This allows ARGOS to acquire a polar orbit from the system's hosts and to provide complete global coverage, which most other LEO satellites cannot offer. For these reasons and the small size/low power transmitters required, ARGOS is currently the most commonly used satellite system for scientific data relay in non-real time.

For CO-OPS needs, the ARGOS system capabilities are very limited. ARGOS satellite beacons transmit data continuously, and satellites receive data as they pass. Since no acknowledge signal is sent back from the receive ground station, redundancy is the only way to guarantee that a message gets through. Once received by the satellite, data are then sent back to ARGOS through a bent-arm mode when available, or store-and-forward mode when it is not. Once the data are processed, the user can retrieve the data in approximately 20 minutes.

While ARGOS cannot be used for real-time data collection, the system is ideal for equipment tracking, since the transmitters for ARGOS are very small and lightweight. CO-OPS currently uses it for the ADCP retrievals. Once the subsurface buoy released from the ADCP platform surfaces, it starts transmitting to ARGOS. The ARGOS system then determines the transmission position and reports it to the user.

Despite the inability to transmit real-time data from the field, the ARGOS system has recently added a two-way data capability to the most recently launched satellites. Only one or two of the newest satellites have transceivers to the field stations onboard at this point, so the user must wait for a satellite with two-way capability to pass. However, as more satellites are launched, the time lag from sending data at the ground to the field station receiving it will become smaller.

Pricing for the ARGOS system is negotiated annually under a JTA (Joint Tariff Agreement) with the French Space Agency. A trial JTA is in place this year, where the charges are based on an equation that considers the type of system ARGOS is being used for, the number of days (divided into ¼ day) the system is transmitting, and the volume of data being transmitted.

Table 5. ARGOS		
System Requirement	**Advantages**	**Disadvantages**
Reliable real-time data		System works by redundantly sending so many copies of a message at predetermined times that a satellite should be in the area – cannot be used to bring back data at a particular time. Even in the best scenarios data takes approximately 20 minutes to return to the user.
Company stability	Operated by NOAA, NASA, and the CNES (French Space Agency).	Most widely used system for scientific data retrieval from the field; however is used more for universities and other non-time critical applications.
Reasonable cost	Cost for the user is determined each year under a JTA (Joint Tariff Agreement).	This year is a 'trial year' for new JTA pricing scheme, so future costs are unpredictable.
Ability to expand usage	Sufficient room for expansion. We are currently using ARGOS for ADCP retrievals by loading them on subsurface floats.	
System versatility	Very versatile within the scientific community because it is a global system that has extremely small, low power transmitters (used for animal tracking).	System cannot be used for time sensitive data retrieval, so there are very limited uses within CO-OPS needs.
Two-way communication capability	Two-way communication has always been available, but the first receiver for this system was just developed this year.	

5.6 Small Business Innovation Research

The Small Business Innovation Research (SBIR) program requires that Federal agencies reserve a portion of research and development (R&D) funding for awards to small businesses. SBIR funding enables small businesses to acquire funding for exploration of the feasibility of a specific technology or idea, as well as additional funding to evaluate the commercialization potential of that technology.

The following paragraphs discuss two technologies that are under development through the SBIR program.

5.6.1 Cellular Coastal Network

With the extensive cellular network now in existence in the U.S., there will be a way to transmit data over this network in the near future. Cell phones can already be used for text messaging, picture messaging, and Internet access, so the capability has been built into the existing system. The Office of Naval Research (ONR) recently identified a data-capable cellular network as being "an enabling technology for NOPP (National Ocean Partnership Program) and IOOS". This system should be an "integration of a wireless 802.16-like system plus satellite communications (like Iridium) into a 'plug and play' network for the US coastal zone". Proposal drafts for this system were due by 1 May 2005, and a Phase I award has been made for this topic.

5.6.2 Data Collection Platform Interrogation (DCPI) Link

An SBIR topic was announced on November 17, 2005 using the two-way data communication capability of the GOES satellite. When it was first designed, the GOES DCS had a DCPI (Data Collection Platform Interrogation) function so that data could be polled back over the satellite. As the system developed, this function was never utilized because the field stations used GPS time rather than relying on a polled mode to ensure transmittal at the proper time. This two-way communication link has since been determined not to meet NTIA (National Telecommunications and Information Agency) authorization criteria and its use discontinued. The SBIR calls for a reliable DCPI transceiver to "permit more efficient use of GOES transponder, enhance data collection for the user, and expand the GOES capabilities." This development would allow small messages to be sent over the GOES satellite, giving remote control to the receiving DCP. This could be used for some basic functions such as rebooting a DCP, switching to backup, transmitting one-time data, imposing an emergency cycle, or shutting down a transmitter.

6.0 Conclusions

CO-OPS has carefully considered the data communications options that are available now and in the near future. By developing the criteria that an effective system must meet and evaluating each system against those criteria, CO-OPS has demonstrated that several systems, though appropriate for some applications, are not the best choices for the transmittal of large data sets every six minutes. Beyond the technical considerations of specific systems, other concerns (of which CO-OPS may lack influence or control) have surfaced and should be addressed. The following is a list of these concerns.

6.1 Concerns

6.1.1 NESDIS/DCS may lack the resources needed to implement future enhancements to the GOES system. As was seen with the DPAS II system, a lack of resources could significantly inhibit the ability of NESDIS/DCS to implement planned improvements. CO-OPS should make an effort to support NESDIS/DCS in these enhancements in any way possible.

6.1.2 NOAA may fail to contribute funds to the DOMSAT satellite system at the next available opportunity. In 2004, NOAA should have contributed $15,000.00 towards DOMSAT development. However, NOAA did not pay its allocated portion and the U.S. Army Corp of Engineers paid NOAA's portion instead. NOAA should contribute to the continuation of the DOMSAT satellite service or to the replacement LRIT system at the next opportunity to ensure that we can continue to use it.

6.2 Recommendations

6.2.1 Continue and expand efforts to build a strong relationship between NOS/CO-OPS and NESDIS/DCS, particularly by supporting the NESDIS efforts to expand GOES capabilities. GOES is and will likely continue to be the premier data communications option for CO-OPS. We must maintain a strong relationship with NESDIS/DCS to ensure that we can continue to expand our usage of this system. We can do this by continuing our support of Satellite Telemetry Interagency Working Group (STIWG) meetings, GOES DRGS and GOES Intra-America conferences, and partnering with NESDIS on key technology issues, especially those related to GOES and DCS.

6.2.2 Fully utilize the GOES DCS and continue the transition to using six-minute GOES for water level stations. GOES DCS communication is the most cost efficient and reliable system available in situations where it is practical to use. Additionally, the stability of a NOAA run satellite makes this the optimal system for most situations. This system should be used whenever possible.

6.2.3 Justify need and assign priority for six-minute data transmissions on each station. NESDIS/DCS has requested that CO-OPS provide a strong justification for the need to obtain six-minute transmittals on all of our water level stations. There may be some instances where six-minute transmittal is not necessary and hourly transmittal would suffice. For example, hydrographic stations are currently only transmitting data from the field hourly and may not need to be returned every six minutes. If these stations are identified, it may reduce urgency for NESDIS/DCS to allocate additional IDs and encourage better relations between NESDIS and CO-OPS.

6.2.4 Pursue a secondary data communications network for situations where GOES is unavailable due to geographic constraints. Several stations are currently unable to transmit data back via the GOES satellite because they are outside of the satellite footprint. A secondary satellite communications system must be developed to allow uninterrupted transmittal of data from these locations.

6.2.5 Investigate the use of a secondary satellite communications system which could be used if additional GOES IDs are not available. If advancements in the existing GOES framework are not completed, it may become increasingly difficult to obtain additional GOES IDs in the future. A secondary satellite communications system that allows for additional frequency allocation should be developed at the lowest cost possible.

6.2.6 Clarify the requirements for transmitting ADCP data and begin investigations of secondary satellite communication options that would meet these requirements. It is not possible to send an entire ADCP data set over the GOES satellite due to the large amount of data that must be transmitted. If all data is to be reported in real-time, a secondary satellite communications system will be required for this purpose. Requirements for this system should be clarified so evaluation of an appropriate system may begin.

6.2.7 Integrate a secondary communications system with flexible two-way communications into our existing framework. Two-way communications are required for system restarts, upgrades, backfilling missed data and changing reporting frequency. The SBIR for the DCPI Link on the GOES satellite addresses this issue. CO-OPS should continue to support this project and consider other alternative two-way communication options for use until this system is available.

6.2.8 Determine the requirements of transmitting ADCP data in real-time. Clarify the requirements to see if it is possible to transmit ADCP data back over a standard 300 baud GOES channel, over a 1200 baud channel, or if a non-GOES method of data retrieval is necessary.

6.2.9 Identify and develop a method to use satellite communication system capable of transferring large data sets. The ADCP has shown a need for large data sets to be transferred from the field in real-time. As technology progresses, more systems with large data sets will be developed. It is unknown at this time if the GOES satellite with access to 1200 baud allotments can transmit large data sets, or if an additional satellite communication system must be used.

6.2.10 Investigate low power communication methods for use on measurement systems with limited energy sources. The ATON-mounted current meters provide an example of a limited power budget influencing the communications options available for use. A standard, reliable system should be used in this type of situation.

6.2.11 Conduct an annual review of existing communications to better identify actual requirements and to ensure against over/understating these needs to partners. With changing technology and priorities, it is difficult to predict CO-OPS' precise communications needs long into the future. This could lead to overstating or understating our long- and short-term needs. By reviewing these needs annually, we can more accurately predict existing requirements and help to ensure that we do not ask our partners to meet over-anticipated needs.

6.2.12 Carefully consider the experiences and decisions of other oceanographic institutions when choosing secondary communication systems. Many other organizations in the oceanographic community have already had experience with various satellite communication options. CO-OPS should pay special attention to the decisions these organizations have made and their experiences with these systems before deciding to pursue specific communication system.

6.3 Summary

CO-OPS requires data communication systems that ensure our ability to provide high quality products and services to our users/stakeholders. These systems must enable us to offer reliable, real-time data collection every six minutes at an acceptable cost, yet be versatile enough to allow integration into many different applications. Currently, the GOES system meets many of our current data communications needs and should remain our primary data collection system to the largest extent available. However, the large data sets produced by ADCPs, stations established outside of the GOES footprint, and the increasing requirement for two-way communication have forced us to consider alternative systems for situations where GOES does not meet our needs.

Based on an extensive review of the available systems, we conclude that the commercial system from Iridium Satellite LLC appears to be the best option because of its versatility on a variety of platforms and its low cost. The Iridium system fulfills each recommendation set forth for a secondary satellite communication system. Additionally, the Iridium system appears to offer these services at the lowest cost of all available secondary satellite communication systems currently available. The intersatellite linking capabilities of the Iridium system allow real-time data collection through short burst data and remote maintenance capabilities through the dial-in connection option. Both services may be used independently or together, making this system the best option to meet CO-OPS' needs.

The following tables offer a synopsis of system comparisons. Table 6 compares the monthly cost for water level stations (<32 bytes) and ADCP data (210 bytes ever 6 minutes). Table 7 highlights the advantages and disadvantages with respect to CO-OPS' requirements.

Table 6.
30 Day / Monthly Cost For Transmitting Data Over Capable Satellite Systems

	WL Station (<32 bytes)	ADCP Data (210 bytes)
GOES	$0.00	$0.00
Iridium - Dial-in	$14,400.00	$14,400.00
Iridium - SBD	$281.49	$281.49
INMARSAT - C	$1,080.00	$7,560.00
INMARSAT - Fleet 33	$12,816.00	$12,816.00
GlobalStar	$550.00	$550.00
ORBCOMM	$329.69	$1,149.00

Table 7.
COMPARISON OF ADVANTAGES/DISADVANTAGES OF EACH SYSTEM

System	Advantages	Disadvantages
Inmarsat	▪ Offers global, real-time messaging ▪ Has a broad user network ▪ Offers broad range of services ▪ Offers two-way messaging	▪ Includes services we do not need ▪ Costs are high for large data sets ▪ Applications are geared toward vessels, not fixed stations
Iridium	▪ Only global, LEO system ▪ Satellites currently in orbit will last until 2014 ▪ Least expensive system evaluated ▪ Has large capacity available ▪ Offers versatile, two-way communication using intersatellite link	▪ Costs vary with service type ▪ Number of new users rapidly increasing ▪ Dial-in through DoD cards requires "red tape"
ORBCOMM	▪ Continental U.S. should have real-time data ▪ Number of ground stations expanding ▪ Acceptable cost for water level station ▪ Works globally on store-and-forward; can be used for non-real time	▪ Works on bent-arm system, so real-time is not always available ▪ Bankruptcy protection since 2000 ▪ No satellites launched since 1998 ▪ Future designs primarily for Coast Guard's automatic identification system
GlobalStar	▪ Seems to have large user base ▪ Acceptable monthly costs ▪ Dial-in and burst data available ▪ Two-way available in spotbeams	▪ Areas of CO-OPS requirement are not covered by spotbeams ▪ Services geared more to voice applications ▪ Alaska, Hawaii and Pacific Islands not covered
ARGOS	Operated by NOAA, NASA< and CNES (French Space Agency) ▪ Sufficient room for expansion ▪ Versatile because of low power transmitters ▪ Two-way communication just developed	▪ No real-time ▪ Future costs are unknown ▪ System cannot b used for time-sensitive data retrieval
Cellular Coastal Network		▪ Not yet developed widely for large data sets

7.0 Acronyms

AC	Alternating Current
ADCP	ACOUSTIC DOPPLER CURRENT PROFILER
ADEOS III	Advanced Earth Orbiting Satellite
AMPS	Advanced Mobile Phone Service
ATON	Aids-To-Navigation
bps	Bits Per Second
CDMA	Code Division-Multiple Access
CDPD	Cellular Digital Packet Data
CGMS	Coordination Group for Meteorological Satellites
DART	Deep-Ocean Assessment and Reporting of Tsunamis
DAS	Data Acquisition System
DCP	Data Collection Platform
DCS	Data Collection System
DOD	Department of Defense
DOMSAT	Domestic Satellite
DPAS	Data Processing and Analysis Subsystem
DRGS	Direct Readout Ground Station
DSL	Digital Subscriber Line
FY	Fiscal Year
GEO	Geostationary Earth Orbit
GOES	Geostationary Operational Environmental Satellites
GPRS	General Packet Radio Service
GSM	Global System For Mobile Communications
ID	Identification
IMEI	International Mobile Equipment Identity
IOOS	Integrated Ocean Observing System
IP	Internet protocol
ISP	Internet service provider
kBaud	Kilobaud
kbits/s	Kilobits Per Second
kg	Kilograms
kHz	Kilohertz
km	Kilometers
LAN	Local Area Network
LEO	Lower Earth Orbiting
LLC	Limited Liability Company
LRIT	Low Rate Information Transmission
MEO	Mid-Altitude Earth Orbiting
METOP	Meteorological Operational Satellite
MHz	Megahertz
MSS	Mobile Satellite System
NDBC	National Data Buoy Center
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration

NOS	National Ocean Service
OFCM	Office of the Federal Coordinator for Meteorology
ONR	Office of Naval Research
OS	Operating System
OSTEP	Ocean Systems Test and Evaluation Program
PMEL	Pacific Marine Environmental Laboratory
PORTS®	Physical Oceanographic Real-Time System
PSTN	Public Switched Telephone Network
RUDICS	Router-Based Unrestricted Digital Internetworking Connectivity
SBD	Short Burst Data
SBIR	Small Business Innovation Research
SIM	Subscriber Identity Module
STIWG	Satellite Telemetry Interagency Working Group
TIROS	Television and Infrared Observational Satellite
U.S.	United States
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USGS	United States Geological Survey

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ONR Broad Agency Announcement

APPENDICES

Appendix A NESDIS Memorandum

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
Silver Spring, Maryland 20910

MEMORANDUM FOR: Richard Barazotto
Director, Office of Satellite
Data Processing and Distribution, NESDIS

FROM: Michael Szabados
Director
Center for Operational Oceanographic Products and Services, NOS

SUBJECT: CO-OPS Future Requirements for GOES DCS

CO-OPS primary mission is to provide operational oceanographic and meteorological information to a broad user base. Our 200 plus measurement systems utilize the GOES DCS as our primary data telemetry method. The DCS provides reliable and timely data communication which is critical to my organization. CO-OPS has begun upgrading the data collection platforms of the Next Generation Water Level Measurement System. This upgrade includes a HDR GOES transmitter. My staff has been working closely with Kay Metcalf who has been extremely helpful and supportive in our efforts to upgrade our field measurement system. As part of this upgrade we are moving to six minute GOES transmissions to provide the real-time information required by our users. Attached are CO-OPS Channel Allocation Requirements for six minute GOES assignments.

CO-OPS has demonstrated both the need and the ability to utilize the DCS HDR capability. The clear requirement exists for faster data throughput to support safe and efficient navigation and to better protect the residents of our coastal communities. By using pseudo-binary encoding, CO-OPS minimizes the data transmit window and makes the most efficient use of satellite time. With GPS timing and 300 baud rates implemented, we are sending real-time oceanographic and meteorological information every six minutes using a five second windows as the standard.

Following the recent Indian Ocean tsunami, a strong and clear requirement has been expressed for all CO-OPS coastal stations to have the capability to acquire data with even shorter sample intervals, and to transmit that data every 6 minutes. Implementation has begun and will continue over the next few years.

Presently CO-OPS has been allocated one channel on the East satellite and one channel on the West satellite, supporting a maximum of 144 platforms transmitting in 5 second windows. While this has met our immediate needs, in the longer term network growth is anticipated on at least two fronts. First, CO-OPS envisions a larger number of stations as we expand the NWLP installations, begin GOES transmissions of Physical Oceanographic Real-Time Systems (PORTS®) data including coastal current observations, and expand transmissions from new bridge clearance/air gap deployments. Second, a larger volume of data from some stations is planned as sensors are added, likely requiring both longer 300 baud transmit windows and 1200 baud channel allocations.

To meet this anticipated growth, we submit the attached channel allocation requirement. The requirements are based upon past expansion rates and planned future growth — it represents our best assessment of our actual needs. The plan also supports significant technological growth for new operational sensors such as waves, water quality, and real-time GPS leveling.

CO-OPS has played an active and supportive role working with your organization in the past, through:

- Active participation in the STIWG (hosting meeting in 2003 and 2004)
- Active participation in GOES DRGS and GOES Intra-America conferences
- HDR demodulator procurements, leveraged with the USGS
- DCS backup plan development and evaluation (an ongoing effort)
- CO-OPS has been recognized as best examples for bandwidth utilization and high level of cooperation.

As a result of this collaboration we have received, and enhanced, the most robust data communications link available to us at present. The GOES/DCS capabilities provides the reliable and timely data telemetry which is critical for CO-OPS to meet our mission goals. It is precisely this need for which the entire GOES/DCS was designed, and we look forward to enjoying continued intra-agency cooperation between NESDIS/DCS and NOS/CO-OPS.

Once you and your staff have had an opportunity to review the CO-OPS requirement, I suggest we meet to discuss this DCS support which is critical to support NOAA's missions.

Attachment (1)

cc: CO-OPS SMT

CO-OPS Channel Allocation Requirement

- In 2005, access to a 1200 baud channel(s) for use development,
- In 2006, add a second 300 baud channel allocation on both East and West satellites, creating a total of approximately 265 six minute allocations (or the equivalent, some windows will be lengthened resulting in fewer slots).
- In 2006, expanded access to 1200 baud channel(s) (ten platforms) to support implementation of long data set transport,
- In 2007, add a third 300 baud channel allocation on the East satellite, creating a total of approximately 325 six minute allocations.
- In 2007, experimental use of the two-way communications capability (through an SBIR developed transceiver),
- In 2008, add a third 300 baud channel allocation on the West satellite, creating a total of approximately 385 six minute allocations.
- In 2008, an additional fourteen 1200 baud slots (a total of 24 platforms),
- In 2009, implementation of two-way communications at 10 locations,
- In 2010, a fourth 300 baud channel on the East satellite, creating a total of approximately 260 slots on the East satellite and 200 on the West, or 460 total six minute sample/five-six second transmit window equivalents.

Attachment 1

Appendix B Developments in Satellite Communications Report

DEVELOPMENTS IN SATELLITE COMMUNICATION SYSTEMS

by David Meldrum, DBCP vice chair

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 October 2004.

Appendices: A. Overview of mobile satellite systems with possible data buoy applications, update 2004

1. INTRODUCTION

Mobile satellite systems (MSS) 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 will offer voice, fax, telex, paging and data capability, whereas little LEOs will 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. A key feature of several MSS currently under development will be their inter-operability with existing public switched telephone and cellular networks, using a dual-mode handset, for example.

Because of 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 MSS 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, with Starsys having been cancelled, Iridium having collapsed (and been relaunched), and Orbcomm, Globalstar and New ICO having been in and out of Chapter 11 bankruptcy protection in the US. Mergers are becoming increasingly common, as market reality forces system planners to cut their losses and pool resources: CCI, Teledesic, Ellipso and New ICO have all signed buy-out or collaboration agreements with cellphone entrepreneur Craig McCaw.

From a technical point of view, some systems do offer significantly enhanced capabilities compared to existing methods. Potential advantages include two-way communication, more timely observations, and greater data rates and volumes. Some systems may also prove to be considerably less expensive than existing channels, although this is as yet unclear. However, dangers will exist for data buoy users of most MSS, 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 on the GTS.

2. DESCRIPTION OF CANDIDATE SATELLITE SYSTEMS

The following paragraphs describe the salient features of those systems that might have a data buoy application. In many cases systems are at an early planning stage, and reliable technical information on which to base an evaluation is unavailable. 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.

2.1 Little LEOs

2.1.1 Argos

Argos has been used by the oceanographic community for more than two 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 now, Argos has flown as an attached payload on the NOAA 'TIROS' weather satellites, but the recent launch on board the Japanese ADEOS-II vehicle and projected launches on board the European METOP platforms mark an important diversification of service provision.

Enhancements to the Argos on board equipment ('Argos-2') include increased receiver bandwidth and sensitivity, with a highly significant move to two-way communication ('downlink messaging') which was piloted aboard the short-lived ADEOS-II, launched in December 2002. Next generation Argos equipment ('Argos 3') will fly from 2006 onwards on board METOP-1, and will offer order of magnitude increases in data rates, as well as two-way communications.

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. The first of the Argos-2 satellites was launched in May 1998, and has been followed in September 2000 by NOAA-L (NOAA-16), and by NOAA-M (NOAA17) in June 2002. NOAA-N will follow in 2005. New direct readout stations continue to be commissioned bringing the current total to more than 40. Additions during the year have included stations in the Antarctic Peninsula (Chile, Meteo Chile), Athens (Greece, CLS), Fiji (Fiji, FMS), Punta Arenas (Chile), Ryad (Saudi Arabia, CACST), Söndre Stromfjord (Greenland, DMI) and Tromsö (Norway, NMI). This continues the programme of improving data timeliness by exploiting use of Argos in 'bent-pipe' mode.

2.1.2 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. After a prolonged period of launcher problems, 35 satellites are now in orbit, making up the complete constellation – although Orbcomm have been awarded a licence for an expansion to a 48 satellite constellation. Of these satellites, 30 are currently operational. The A, B, C and D planes are at 45° inclination and therefore have poor coverage at high latitudes: only two satellites, in the F and G planes (70°), offer a near-polar service, and these have proved to be unreliable. No further launches have been announced, although the satellites are starting to become quite elderly, and one would expect that replenishment will have to start soon

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). Although there have been significant problems with interference close to urban areas, this is not expected to impact offshore operations, and trials of the system have been encouraging. Operational experience of the system is growing rapidly, although it remains difficult to obtain detailed technical information from Orbcomm.

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.

Authorised transceiver manufacturers include Elisra (Stellar), Quake and MobiApps. All manufacturers offer units with integral GPS. Quake sell a fully integrated unit which features a built-in antenna as well as GPS. Prices of most units are falling, with models now available for around $500.

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. Currently subscription costs within Europe are on a fixed cost per unit with two bands of usage (above and below 4kbytes per month with a typical monthly rate for the higher band being $70). A fully metered billing system based on users' actual data throughput was to be implemented in July 2000 but was postponed, officially due to technical problems. If this billing system is implemented with the planned charges ($6/kbyte) then it will result in a massive increase in airtime costs for any user with data rates over 0.5 kbytes/day. Metered billing is apparently implemented outside Europe.

Orbcomm has suffered financial difficulties, and filed for 'Chapter 11' bankruptcy protection in September 2000. The parent company, Orbital Sciences Corporation, has put together a new consortium to run Orbcomm. The outstanding debts are believed to stem largely from the system rollout phase, with net running costs being of much smaller concern. Industry confidence in Orbcomm continues to grow, largely because of the commitment of many third-party equipment and system manufacturers to the success of the system, and evidence of increasing service take-up by a diverse range of customers. Lately, the USCG have awarded Orbcomm a contract within their automatic ship identification (AIS) programme.

2.1.3 Vitasat/Gemnet

This was a 36 + 2 satellite constellation proposed by CTA Commercial systems. Their experimental satellite was the failed Vitasat launch in 1995. CTA is reported to have been taken over by Orbital Science Corporation, the parent organisation of Orbcomm, and the 36-satellite Gemnet component has been cancelled. However, the volunteer VITA organisation still exists and currently has one satellite in orbit, with plans to rent bandwidth on two other existing satellites, HealthSat-2 and UoSat-12. This proposal received FCC clearance in December 2000, and the company have now brought HealthSat-2 on line. The main mission is to offer low-cost messaging services to developing countries.

2.1.4 Faisat

The Final Analysis company have planned this 32 (+ 6 spare) satellite constellation to provide data messaging services, principally aimed at small messages (~ 100 bytes), but with support for larger messages as well. It will operate in both bent-pipe and store-and-forward modes. The first satellite launch, on the Russian Cosmos vehicle, was scheduled for early 2000, but nothing has been reported. Further launches were to have occurred roughly twice a year. The system received FCC authorisation in April 1998. A test satellite (also part of the Vitasat system) was launched in 1997. Despite the apparent lack of activity, the website continues to be updated.

2.1.5 Gonets

Two GONETS LEO messaging systems have been proposed by the former Soviet Union, using both UHF and L/S-band communications channels. Both will offer true global coverage from high inclination 1400 km orbits. One system, GONETS-D already has 8 satellites in orbit with a further 36 planned. No operational experience has been reported to date.

2.1.6 AprizeSat

Formerly known as LatinSat, this recent store-and-forward system uses low power ‘nanosatellites’ (20 cm cubes) in polar orbits to communicate with small user terminals. The satellites employ passive attitude stabilization and are said to be relatively inexpensive to construct and launch. Mobiles establish 2-way communication with the satellites at 402 MHz, message traffic currently being downloaded to a single ground station in Bermuda. The system currently has four satellites in orbit and is targeted at asset tracking. Plans include a 48-satellite constellation and a more extensive ground station network. Little further is known at present.

2.2 Big and Broadband LEOs

2.2.1 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. Discussions are underway regarding the implementation of a ‘soft-SIM’ user identification facility as a way of minimizing the costs of system membership for occasional users such as Argo floats, which might only place a call once every 10 days.

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 cost is currently ~$1/kbyte, plus a monthly fee. 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.

Iridium continues to add to its constellation, with five new satellites launched in February 2002, and operational experience with the data service is starting to grow. However it is likely that its future survival will depend heavily on continuing support from defence interests.

2.2.2 Teledesic

This ‘Internet in the Sky' system planned a 288 (originally 840) LEO constellation to carry global broadband services such as video conferencing, the Internet, etc. It recently merged with Celestri, another proposed broadband LEO system. Since then there has been some doubt over the actual makeup of the combined constellation. Teledesic has suffered because of the financial difficulties of Iridium, as Motorola, one of Teledesic's primary investors and head of the industrial partnership developing the system, transferred engineering effort and funding to prop up Iridium. Teledesic has received FCC licensing for operations in the USA, and recently joined forces with Craig McCaw's New ICO. The constellation plan has been further trimmed to 30 MEOs, and the company announced in October 2002 that it was suspending its satellite construction work.

2.2.3 Globalstar

Globalstar was Iridium's main competitor in the mobile satellite telephony market. 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.

Data services at 9600 bps are now available, using a dedicated modem. Globalstar also has a second generation system planned, said to involve 64 LEO satellites and 4 GEO satellites. Little else is known about the planned enhancements of this system.

2.2.4 Other Systems

Other planned big LEOs still showing signs of life include Ellipso (a hybrid elliptical LEO/MEO system, now merged with Teledesic and New ICO), LEO SAT Courier (an ambitious German led system) and SkyBridge.

2.3 MEOs

2.3.1 New ICO

New ICO (formerly ICO Global Communications) was the third of the three main players in the global satellite telephony market. However it also has suffered severe financial difficulties and filed for Chapter 11 bankruptcy protection in August 1999, just two weeks after Iridium. The system, formerly known as Inmarsat-P but now fully autonomous, will use a constellation of 12 MEO satellites backed by a 12-station ground segment to provide a truly global voice, fax, data and messaging service. The aim is to complement and be inter-operable with existing digital cellular telephone networks. Prior to filing for bankruptcy protection, the first launch was planned for late 1999 with commercial service roll out scheduled for the third quarter of 2000. The company emerged from Chapter 11 protection in May 2000, and the first satellite was launched in June 2001, with service scheduled to start in 2003. However, ICO appear not to have launched any more satellites since 2001 and there is still no definite date for service rollout.

When the complete constellation is in service two satellites will always be visible from any point on the earth's surface. The space segment is being built by Boeing Satellite Systems. Data rate will be 9600 bps. Many large manufacturers are engaged in developing dual mode ICO/cellphone handsets. An ICO ‘engine’, is to be defined for the benefit of third-party equipment manufacturers (OEMs).

New ICO have joined forces with Teledesic (both owned by ICO-Teledesic Global), with major revisions to the scope of both systems. In particular New ICO is now putting a far greater emphasis on data services, rather than voice services which are now widely recognised as holding smaller potential. The company continues to face a number of regulatory difficulties, and is currently seeking the relicensing of its spectrum allocation.

2.4 GEOS

2.4.1 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.

2.4.2 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.

2.4.3 Inmarsat Mini-M, 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.

3. ACKNOWLEDGEMENTS

The assistance of Richard Winterburn of MES Communications Ltd in the preparation of this report is gratefully acknowledged.

4. REFERENCES

1. Hanlon, J (1996). Emerging LEOs telemetry options for use in scientific data buoys - a marine instrument manufacturer's perspective. In: *Proceedings of the DBCP Technical Workshop, Henley on Thames, October 1996*. DBCP Technical Document No 10, WMO, Geneva.

2. Hoang, N (1999). Data relay systems for drifting buoys utilizing low-earth orbit satellites. In: *Proceedings of the DBCP Technical Workshop, Hawk's Cay, October 1998*. DBCP Technical Document No 14, WMO, Geneva.

5. USEFUL WEB SITES

5.1 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 Encyclopaedia	*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/*

5.2 Specific operators

AprizeSat	*http://www.aprizesat.com*
Argos	*http://www.cls.fr/*
	http://www.argosinc.com/
Ellipso	*http://www.ellipso.com/*
Final Analysis	*http://www.finalanalysis.com/*
Globalstar	*http://www.globalstar.com/*
GOES	*http://www.goes.noaa.gov/*
Inmarsat	*http://www.inmarsat.org/*
Iridium	*http://www.iridium.com/*
LEO SAT Courier	*http://www.satcon-de.com/*
METEOSAT	*http://www.esoc.esa.de/external/mso/meteosat.html*
New ICO	*http://www.ico.com/*
Orbcomm	*http://www.orbcomm.com/*
Ocean DataLink (ODL)	*http://www.viasat.com/*
Skybridge	*http://www.skybridgesatellite.com*
Thuraya	*http://www.thuraya.com/*
VITA	*http://www.vita.org/*

Overview of mobile satellite systems with possible data buoy applications - update 2004

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, are scheduled
ECCO (CCI Global)	On hold		LEO	GPS required	voice/data	Handheld	TBD	12 equatorial satellites planned by 2003. Status questionable – merged with ICO-Teledesic Global
ELLIPSO	Licensed On hold		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	Licensed On hold		Little LEO	GPS required	data: TBD	TBD		6 satellites for utility metering (aimed at Continental US only initially)
FAISAT	Licensed On hold	Service 2002+	Little LEO	GPS required	data: 128 bytes	Handheld	10	38 satellites 2000+ Test satellite launched 1997
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) Limited coverage due to lack of ground stations. Financial difficulties.
GOES, Meteosat, GMS	Operational		GEO	GPS required	data: various options	Laptop	10	4 satellites; directional antenna desirable NOAA / ESA / Japanese met satellites.
GONETS-D	Pre-operational		Little LEO	GPS/ Glonass	Data	Handheld	TBD	8 satellites in orbit, 36 more planned

GONETS-R	Planned On hold?		Little LEO	GPS/ Glonass	Data	Handheld	TBD	48 satellites planned
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
ICO (New ICO)	Licensed On hold?	Service 2003	MEO	GPS required	voice/data: no maximum	Handheld	1	Global voice and packet data services. Recently merged with Teledesic to form ICO Teledesic Global. 12 satellites planned, only one launched so far.
Iridium	Revived	Service resumed 2001	Big LEO	GPS preferred	voice/data: no maximum	Handheld	1	72 satellites in orbit
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
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	Licensed On hold	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	Licensed On hold	Service Late 2004	Big LEO	GPS required	Broadband			288 LEOs planned, now reduced to 30 MEOs FCC licence granted, merged with new ICO
Temisat	Experimental		Little LEO		Data			7 satellites planned for environmental data relay. 1 satellite launched 1993.
Thuraya	Operational		GEO	Integral GPS	Voice/data	Handheld		1 multiple spot beam satellite in orbit (over Middle East), 1 planned
Vitasat	Pre-operational		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.

Appendix C Alliance for Coastal Technologies Data Telemetry Technologies for Coastal Ocean Observations

Workshop Proceedings

Data Telemetry Technologies for Coastal Ocean Observations

St. Petersburg, Florida
April 30-May 2, 2003

Funded by NOAA's Coastal Services Center through the Alliance for Coastal Technologies (ACT)

UMCES Technical Report Series: TS-416-03-CBL / Ref. No. [UMCES]CBL 03-317

An ACT 2003 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Data Telemetry Technologies for Coastal Ocean Observations

St. Petersbug, Florida
April 30-May 2, 2003

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner, the College of Marine Science at the University of South Florida in St. Petersburg, Florida.

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitat.

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ACT Workshop: Data Telelmetry Technologies for Coastal Ocean Observation

Executive Summary

The Alliance for Coastal Technologies (ACT) Workshop "Data Telemetry Technologies for Coastal Ocean Observations" was held in St. Petersburg, Florida, April 30-May 2, 2003, with sponsorship by the University of South Florida, College of Marine Science, an ACT partner organization.

The workshop was designed to summarize the existing telemetry technologies for coastal ocean observing systems and to address their shortcomings for the purpose of facilitating future technological advancements, with a focus on wireless technologies. Representatives from academia, industry, and government agencies were invited to participate in this three-day workshop. The goals of the workshop were to explore technologies now in place or soon to be available and to make strategic recommendations for the future development and application of technologies for the telemetry of data from coastal ocean observing systems.

A general consensus emerged that a wireless network encompassing all coastal waters of the US be developed and that such a network was possible using existing technologies. At the close of the workshop, participants voted on various recommendations for the data telemetry community. The priority recommendations included developing protocols and standards for data telemetry, establishing a forum where developers and users can arrive at a consensus on protocols and standards for a fully functioning network, defining the existing infrastructure that could be utilized in developing a coastal ocean network system, and determining both geological and technical boundaries of such a network. It was also suggested that ACT should serve as a clearinghouse for information on available technologies and facilitate the further development of fundamental technologies that would eventually be part of the coastal ocean network.

Alliance for Coastal Technologies

There is widespread agreement that an Integrated Ocean Observing System is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/ development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,

- A comprehensive data and information clearinghouse on coastal technologies, and

- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring and predicting the state of coastal waters. The workshop goals are to both help build consensus on the steps needed to develop useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and that represent a broad range of environmental conditions for testing. The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT activities.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.actonline.ws.

Goals for the Data Telemetry Workshop

The ACT workshop on data telemetry technologies for coastal ocean observations was convened April 30-May 2, 2003 in St. Petersburg, Florida. The focus of the workshop was on technologies for bringing data from remote ocean observation platforms back to the shore-based data network. The focus was narrowed further to concentrate on wireless technologies, as cabled observing systems are being treated extensively elsewhere (for example, see http://www.coreocean.org/SCOTS/). The workshop addressed the following goals:

(1) to explore technologies now in place or soon to be available for the telemetry of data from coastal ocean observing systems

(2) to make strategic recommendations for the future development and application of technologies for the telemetry of data from coastal ocean observing systems

Organization of the Data Telemetry Workshop

The workshop was sponsored by ACT and hosted by the University of South Florida (USF) College of Marine Science, an ACT partner institution, in St. Petersburg, Florida. This telemetry workshop was organized by Mark Luther at the University of South Florida. Robert Heinmiller from Omnet, Inc., served as the workshop's facilitator. Participants were invited to represent a broad range of technology developers, technology providers, and end-users of telemetry technologies, including both academic researchers and resource managers, as well as to provide geographic diversity. A list of participants and the workshop agenda appear as appendices.

Participants arrived Wednesday, April 30th for an evening reception and dinner. Thursday morning and early afternoon plenary presentations were given on the present state of data telemetry technologies by the following participants: David Meldrum from the Scottish Association for Marine Science, Scott McLean from Satlantic, Inc., Steve Piotrowicz from Ocean.US, Tom Herrington from Stevens Institute of Technology,

James Sprenke from NOAA, Eric Terrill from Scripps, and Michael Luby from Digital Fountain. A demonstration of a Sensor Web, an intelligent, wireless, sensor network, was given by Kevin Delin from NASA's Jet Propulsion Laboratory (http://sensorwebs.jpl.nasa.gov). Presentations in .pdf format and movies in .mpeg format of applicable discussion are available for download on the ACT website at http://actonline.ws/USFworkshop.html.

The participants broke into 3 working groups in the afternoon. Working group discussions focused on four subjects:

(1) *What technologies are currently available?*
(2) *What are the roadblocks?*
(3) *What is on the wish list?*
(4) *Where do we go from here?*

At the end of the day, the working group leaders summarized the results of the discussions of the three separate groups. On the evening of the second day, ACT's Director, Ken Tenore, gave a presentation on ACT's vision and direction. On the last day, participants reached a consensus on a master list of recommendations that were discussed during the workshop and voted to prioritize these recommendations.

Overview of Telemetry Options for Coastal Ocean Observations

The following is a summary of the presentations made in the plenary session compiled by Lauren Wetzell and Sherryl Gilbert. Specific claims as to data rates, costs, or other details of systems described are quoted as presented at the workshop and are subject to change. Mention of specific commercial products or services are for purposes of illustration only and are not meant to be an endorsement of a particular product or service.

The need for telemetry of coastal ocean observations has become more demanding. The problem at hand is how to get data back from remote platforms located some distance from population centers, either off shore or along the coast, so that they may be accessed from the land-based data network. For platforms in urban areas, cellular-based networks are possible. For systems within 30 nautical miles (nm) of populated areas, line-of-sight radio communications are possible. Satellite communications become necessary for greater distances. Currently, most data communication systems involve two components, above and below sea, to link back to the shore-based communications network (Figure 1).

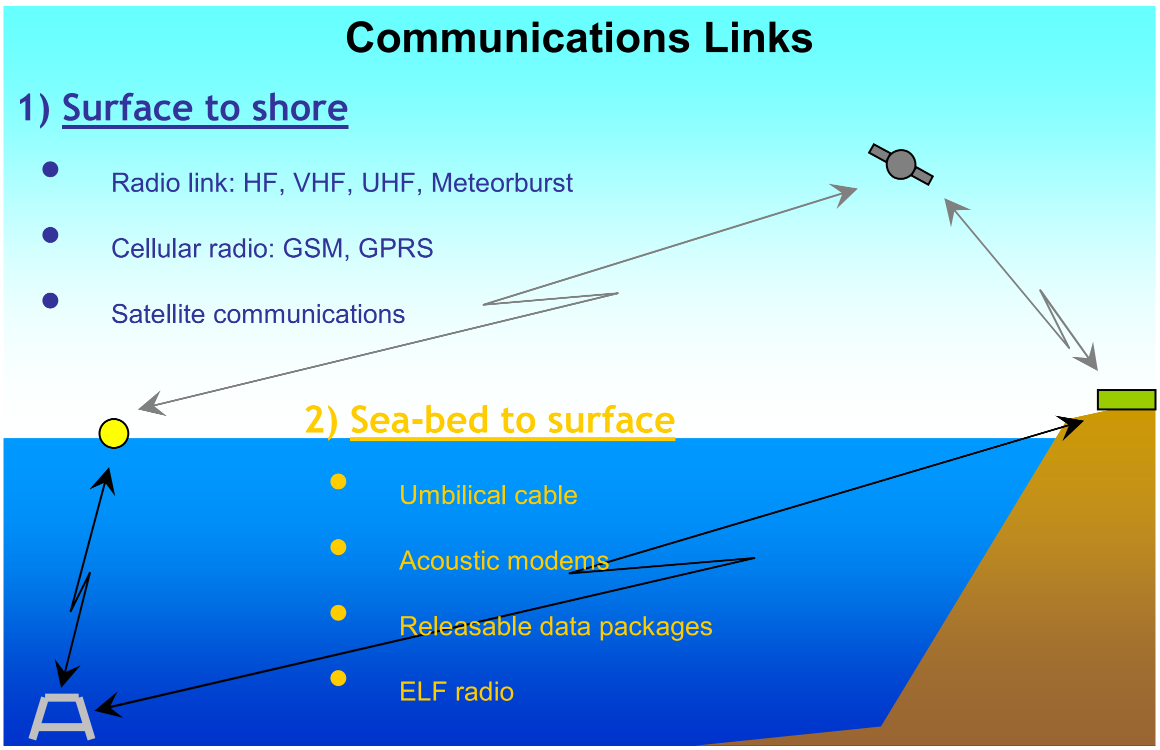

Figure 1: An illustration describing the two components, currently, involved in satellite communications. (*Dave Meldrum, Scottish Association for Marine Science*)

The surface-to-shore linkages are generally obtained by radio, cellular radio, or satellite communications. Linkages from the seabed-to-surface are usually obtained either by an umbilical cable, acoustic modems, releasable data packages, or ELF radio. Those systems using an umbilical cable are challenged with complex designs due to the wiring and cost of the massive cable. However, a protocol for networking sensors has been suggested as a solution. Acoustic modems serve as another method to communicate information in the water column. New modulation techniques promise improved performance. However, these energy intensive systems function better in deep water and they are subject to noise, shadow zones, multipaths, and reverberations.

In selecting above or below water systems, and especially for satellite systems, the user must consider the following options: bandwidth, timeliness, availability, geographical coverage, energetic and economical costs, physical size, reliability, and future applications. A summary of satellite links available for ocean observing systems can be accessed using the following link: http://www.dbcp.noaa.gov/dbcp/index.html. Overall, 32 systems are available in the DBCP catalogue of which 9 are operational, 2 are pre-operational, 3 are experimental, 3 are cancelled, and 15 are on hold. Reliability and future applications for satellites available to ocean science can be classified as secure or nonsecure. Argos, Inmarsat, and GOES are satellites considered to be secure, in the sense that they are mature systems with promise of longevity, where as Orbcomm, Iridium, Globalstar, New ICO, and Ocean Data Link are considered nonsecure, in the sense that their future is somewhat uncertain (Figure 2).

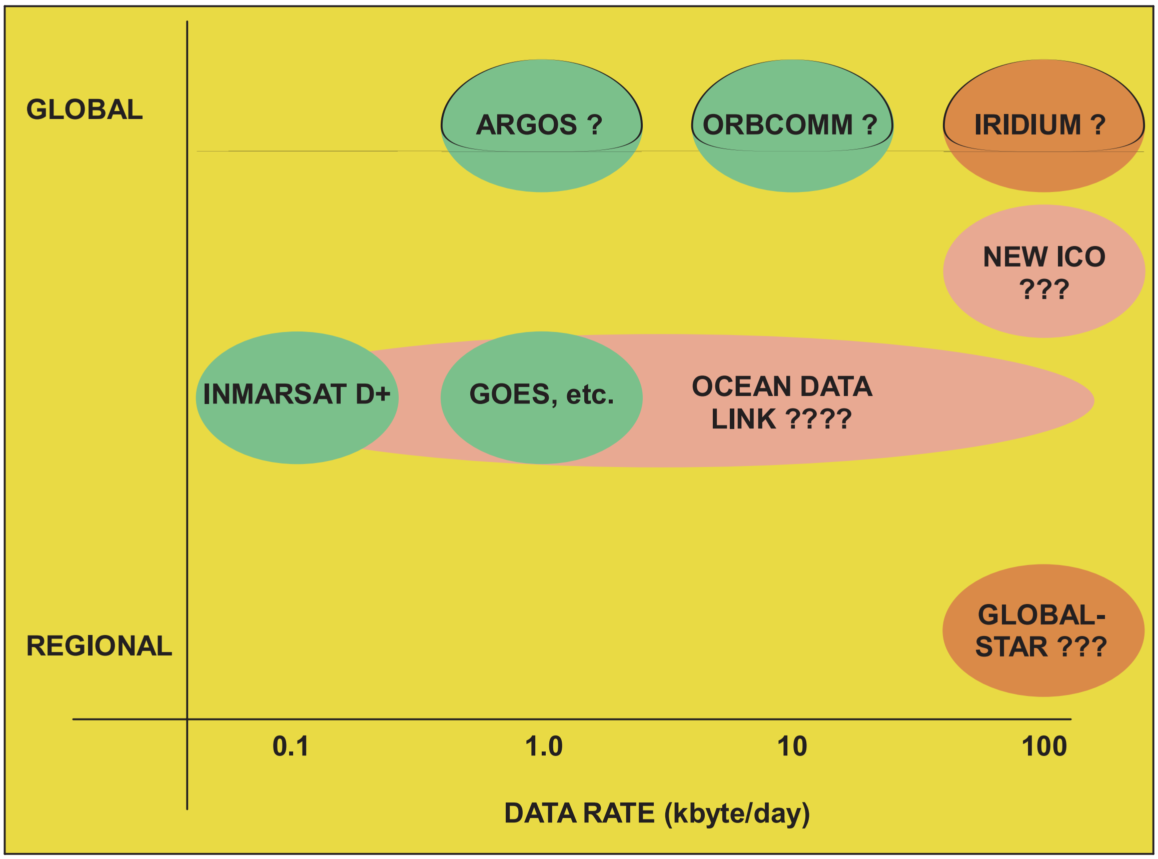

Figure 2: Several key features regarding satellite linkages. The question marks indicate non-secure systems. *(Dave Meldrum, Scottish Association for Marine Science)*

Argos, Iridium, and Orbcomm systems will be described in more detail. Currently, numerous satellite systems are either being constructed or designed. Most of these systems will be fully commercial while few systems will include marine data within their business plans and furthermore, marine data users will have little influence over system operation or cost. The satellite communication systems currently available to buoy operators are summarized in Table 1 on the following page.

Table 1: A summary of satellite communications currently available to buoy operators (GEO=geostationary and LEO=low earth orbiting). *(Dave Meldrum, Scottish Association for Marine Science)*

Satellite System	Transmission Type	Satellite Type	Throughput Rate
Inmarstat D+	Pager	GEO	< 1 kbyte/day
GEOS, Meteostat…	Messaging	GEO	< 5 kbyte/day
Argos	Messaging	LEO	< 5 kbyte/day
Inmarstat C	Messaging	GEO	< 10 kbyte/day
Orbcomm	Messaging	LEO	< 50 kbyte/day
Iridium	Voice	Big LEO	< 1 mbyte/day

1. Satellite Systems

Argos

Argos is a global telemetry and geo-positioning satellite-based location and data collection system dedicated to monitor and protect the environment. This system was established in 1978 between three agencies: NOAA, NASA and French Space Agency (CNES). Currently, over 7 thousand Argos transmitters are operational globally where 2 satellites are simultaneously in service on polar, sun-synchronous, circular orbits, to provide real-time and full global coverage (http://www.argosinc.com). Traditionally Argos served as an oceanographic system with a 1-way blind transmitter. Today, Argos is advancing towards a more internet basis, operating at 401.65 MHz (clean part of the spectrum), and employing a 2-way transmitter system. The maximum message size is 32 bytes and the daily maximum is approximately 1 kbyte. Although the user's cost is high, one of the major advantages of the Argos system lies within the delivery of data being packaged and quality controlled.

Orbcomm

Orbcomm is a wireless telecommunications company utilizing today's email system for message delivery as the primary option for delivering data. The company provides near real-time 2-way digital messaging, data communications, and geo-positioning services using a global network consisting of 30 Low Earth Orbit (LEO) satellites with terrestrial gateways. Private and public networks, such the Internet, can be connected via these satellites and gateways (http://www.orbcomm.com). The company's major market share is asset tracking and remote monitoring. A 5W transmitter is used to provide communications where the location may be computed by the subscriber's mobile or GPS. The systems can send up to 8Kbytes in a single message. Although better through put can be achieved using 1-2K message sizes. In the store and forward mode, a Global Gram can be sent with a max payload of 229 bytes per transmission. The approximate maximum throughput is 50 Kbytes/day. If your application needs to send this amount of data you probably are better using Iridium. Orbcomm is best suited for smaller payloads. The European service rate is approximately $2 per day regardless of the data volume. The service has some limitations, including that it is not licensed world-wide and that it operates on the noisy side of the spectrum (138-150MHz). Additionally, the company has 2 working polar orbiting satellites operating in 'hybrid mode' resulting in additional loss of performance when operating within these extreme geographical areas. Orbcomm provides excellent coverage if the subscriber is near one of its five U.S. Gateway Earth Stations (GES's), three South American GES's, two European GES's, or the Korean, Malaysian, or Japanese Gateways. The data delivery is in the form of email, but it is not processed when it is sent back to the user, and for some customers that do not have backend software this can pose a problem. However, there are Orbcomm Value Added Reseller's such as SASCO that serve the marine industry. See SASCO at: http://www.sasco-inc.com. The satellite modems for Orbcomm start as low as $200.00 making it the least expensive satellite solution in the world. The leading manufacture of Orbcomm modems is Quake Global located in San Diego. You can check out their website at http://www.QuakeGlobal.com or ask USF about their BSOP project which uses the Quake Modem.

Iridium

Iridium is a satellite-based, wireless communication system providing complete coverage of the globe (86% landmass and ocean coverage). Using 66 LEO satellites operated by Boeing, Iridium provides mobile satellite voice and data transmission (http://www.iridium.com). The service operates along the L-band, approximately 1.5 GHz, which is a relatively clean part of the spectrum. Iridium is a 2-way system with a compact antenna and provides true real time service using a 10W transmitter and a dial-up modem with the maximum throughput greater than 1Mbyte/day. The subscriber's location may be computed by GPS. Commercial rates are about $1 per minute with a data rate of 2.4kbps. Similar to Orbcomm systems, the company's major weakness for operational users is that the sensor data is neither processed nor packaged for the end user. Overall, Iridium has an excellent potential for higher data volumes of up to 20 kbyte/sec at 10 cents per kilobyte or less. The subscriber can have interactive control of the mobile and the mobile can initiate communication when on the surface. Remote platform owners may find it advantageous to move from interactive connections to datagram (SBD) service. Several recommendations have been suggested for operational users when selecting satellite systems. For example, it is highly suggested that the user investigate the system's geographical coverage, data rates, and the system's anticipated lifetime. Additionally, the user should determine if the delays, outages, error rated, energy costs and financial costs are acceptable. Overall, the user is recommended to perform practical trials of the system before committing to their service.

Inmarsat (InmarsatC, Inmarsat D+, Inmarsat Mini M)

Inmarsat is a mobile satellite communications operator that grew out of the maritime community's need for modern communication services. The company presently serves a broad range of markets. Starting with a user base of 900 ships in the early 1980s, it now supports links for phone, fax and data communications at up to 64kbit/s to more than 250,000 ship, vehicle, aircraft and portable terminals. That number is growing at several thousands a month. The satellites are controlled from Inmarsat's headquarters in London. Data on the status of the nine Inmarsat satellites is supplied to the SCC (Satellite

Control Center) by four tracking, telemetry and control (TT&C) stations located at Fucino, Italy; Beijing in China; Lake Cowichan, western Canada; and Pennant Point, eastern Canada. There is also a back-up station at Eik in Norway. Traffic from a user terminal passes via a satellite and then down to a land earth station (LES), which acts as a gateway into the terrestrial telecoms networks. There are about 40 LESs, located in 30 countries. Keystone of the strategy is the new Inmarsat I-4 satellite system, which from 2005 will support the Inmarsat

Broadband Global Area Network (B-GAN) - mobile data communications at up to 432kbit/s for Internet access, mobile multimedia and many other advanced applications. For additional information please visit www.inmarsat.com.

Globalstar

Globalstar is a provider of global mobile satellite telecommunications services, offering high-quality, low-cost voice and data services to businesses, communities and individuals around the world. Signals from a Globalstar phone or modem are received by the company's constellation of 48 Low Earth Orbiting (LEO) satellites and relayed to ground-based gateways, which then pass the call on to the terrestrial telephone network.

Additional services include the internet and private data network connectivity and position location. The company's data modem products can also be used for asset tracking and environmental telemetry applications. Globalstar intends to continue expanding its operations to provide service in the few remaining land areas not covered today, as well as across mid-ocean regions. Products and accessories will also continue to be developed and upgraded to make the service even more useful. Please visit www.globalstar.com for more information.

NOAA/NESDIS will be conducting a small study of the commercial satellite telemetry providers as part of its regulatory responsibility to prevent government competition with the commercial space sector. Candidates for this study include Inmarsat, Orbcomm, Iridium, and Globalstar. This written report will include future system plans, description, financial status, and a summary of the system products and services.

Several recommendations have been suggested for operational users when selecting satellite systems. For example, it is highly suggested that the user specifies the system's global regional coverage, data rates, and inquires about the system's anticipated lifetime. Additionally, the user should examine if the delays, outages, error rates, energy costs and financial costs are acceptable. Overall, the user is recommended to perform practical trials of the system before committing to their service.

2. Cellular

Cellular technology provides users with low equipment costs because of its already established network. It has large spatial coverage with a reliable already existing network. However, this technology has poor coastal ocean coverage and has a tendency to become overwhelmed by users during crisis, as happened during the events of 9/11/01. In addition, low to medium bandwidth can lead to low transmission speeds. This system also has a continuous operational cost associated with it. Older telephone systems use analog coding. The electrical variations induced into the microphone are transferred directly as electrical signals. The magnitude of the electrical signal is equivalent to the magnitude of the original signal. More modern telephone systems use digital coding. The electrical variations induced into the microphone are sampled, and each sample is then converted into a digital code. There are three standards for cellular communication presently in use. Advanced Mobile Phone Service (AMPS) is an older analog standard that is being phased out in most areas. True internet connectivity is provided over AMPS using Cellular Digital Packet Data (CDPD), with bandwidths of 19.2 kbit/sec. CDPD competes for limited analog cellular channels with voice traffic, leading to high latency during peak usage periods. Code Division-Multiple Access (CDMA) is a digital standard that works by converting speech into digital information, which is then transmitted as a radio signal over a wireless network. It uses a unique code to distinguish each different call, enabling many more people to share the airwaves at the same time. Global System for Mobile Communications (GSM) is an emerging international standard for digital cellular communications. Under the GSM standard, General Packet Radio Service (GPRS) enabled networks offer 'always-on', higher capacity, Internet-based content and packet-based data services. This enables services such as color Internet browsing, e-mail on the move, powerful visual communications, multimedia messages and location-based services (see http://www.gsmworld.com/technology/gprs/index.shtml).

3. Point to Point Radio

Line of sight (LOS) technology provides users with a high bandwidth that is power efficient for larger transmissions. There is also no cost associated with these transmissions. However, users are limited by both range and antenna height. Two commonly used radios are the FreeWave spread spectrum radio-modems, which provide RS233 serial communications at up to 115 kbit/sec over ranges of up to 100 km, and the Cisco wireless Ethernet transceivers, which provide 802.11 wireless Ethernet over ranges of up to 32 km. Appropriate use of repeaters can greatly extend the range of LOS radio communications. There are many other packet data radio modems and transceivers on the market. It was noted that here is a new standard emerging for long-range wireless Ethernet, termed 802.16, that may be appropriate for coastal observing system networks.

4. Underwater Acoustic Communications

Benthos

The ATM 88x modem is the newest generation of underwater modem from Benthos. The modems will transmit anything typed at an attached keyboard. They will likewise transmit anything received over an RS232 com port. The units can be put into a sleep mode, to be awakened with either acoustic or com port data. The ATM 88x will transmit at any available signaling scheme, up to 15,360 bps. The ATM 89x units, using an attached floating point based DSP on a daughter board, can receive these high speed data. The daughter board currently is available with the deckbox. Range rate compensation for relative speeds up to 6 kts is provided for all signaling schemes. A distant modem can be reached via another modem when the intermediate unit is put into a relay mode. Every message received by this unit is automatically retransmitted to the intended unit. We can provide conversion among frequency bands and modulation schemes to suit particular requirements. For example, one may wish to achieve long range (5-7 km) in open sea, which would argue for the low frequency (LF) band, but translate the message to the high frequency (HF) band for reception by nearby divers.

5. Software Algorithms

Software algorithms are necessary for ensuring that data are delivered accurately and efficiently over potentially unreliable communications networks. One such solution that was presented at the workshop is from Digital Fountain. The driving force behind Digital Fountain's speed, predictability and control is the company's patented Meta-Content technology, a networking innovation that dramatically simplifies the processes required to completely and perfectly deliver data over any network, regardless of impairments like packet loss and delay. The original document is cut into slices and sent in sequence. Every slice must be received in order-lost slices are re-sent. Since TCP cannot continue with too many missing slices, it responds to loss by lowering the send rate. Digital Fountain's technology is shown to overcome these obstacles in a highly efficient manner (see http://www.digitalfountain.com/calc/adv.htm for additional information).

Current Technological Impediments

There is a clear need for advancement in telemetry systems. While current technologies are useful, significant limitations and short-comings exist. The following list addresses these issues.

1. *Individual solutions to individual problems*

   Technologies unique to each organization or agency tend to stay within that particular organization or agency. Currently, no common national oceanographic network exists.

2. *Lack of agreements and standards*

   The coastal oceanographic community currently lacks any standardized format or code for communicating real-time oceanographic data.

3. *Bandwidth*

   Bandwidth is not only a problem for deep ocean projects. Surface observations are delayed by either the inadequate throughput of static platforms or the bottleneck effect of too many users at once with dynamic platforms (eg. 9/11).

4. *Cost*

   High maintenance costs are associated with coastal observation sites, including set-up, sustaining, and repairing damaged instrumentation.

5. *Reliability*

   In addition to tackling security risks associated with wireless networks, users often deal with intermittent connectivity.

6. *Coverage*

   Satellites densely cover equatorial and mid-latitude regions, however, polar regions are poorly spatially resolved. Poor temporal resolution is also an issue. LOS radio technologies suffer from limited range, while cellular communications (which employ LOS technologies) have limited coverage areas.

7. *Long term stability of providers*

   Several satellite providers are in tenuous business positions. Technologies become obsolete and are discontinued (i.e., CDPD).

8. *Economics of scale*

   The ocean observing community at present is too small to exert much influence over the wireless communications market.

Workshop Recommendations

The following recommendations are the result of discussions during the workshop. It was generally agreed that the US coastal ocean observing community should strive to establish a wireless network that would encompass all the coastal waters of the US. Most of these recommendations address steps needed to establish such a network. Some of these recommendations are directed specifically to ACT and others are for the data telemetry community at large. Recommendations are listed in order of priority as determined by votes cast by all workshop participants.

1. Protocols and standards for data telemetry need to be developed and agreed upon. The data telemetry community needs to establish an underlying level of uniformity in data telemetry techniques including but not limited to bandwidth requirements, data storage, instrument communication, data compression, connectivity, and networking. There needs to be a forum where developers and users establish what these protocols and standards should be for a fully functioning network.

2. ACT may serve as a clearinghouse for information on available technologies.

   Although the present goal of ACT is to serve as a clearinghouse for existing work on sensor technology, the participants' consensus recommends ACT expand or redefine its mission to include the networking technologies necessary to get data back from some defined coastal hot spot. This suggestion adheres to ACT's primary mission because the development of communications from the sensors to the shore, or from sensor to sensor, are fundamentally part of the sensor platform and it is consistent with the goal of having a truly integrated system. The group's interest lies in populating this clearinghouse with useful and current information for others to draw from. Additionally, this clearinghouse should be moderated to ensure accuracy of the information.

This clearinghouse can also serve as an online center for the discussion and dissemination of information about development efforts in coastal wireless technology. Users can begin populating the knowledge base as a way to initiate this forum. This clearinghouse can be a continuingly updated picture of technologies that are currently available, but not a library of engineering "fixes" or "work-arounds". Furthermore, the clearinghouse should serve as a forum where users share technological advancements on current projects, problems and associated solutions to these projects, and what kinds of advancements need to be made. This forum can exist in the form of a "chat room," however, a moderator would be recommended.

3. First develop simple and robust technologies, eventually working towards technologies on the near horizon, pushing the envelope of innovative and emerging technology. Initial efforts should focus on durability and longevity in creating the baseline network. This initial effort would serve as a platform for new technological advancements.

4. Identify the existing infrastructure functionally designed for global network systems including wireless and /or fiber optics communications. First, users and developers need to investigate and catalog existing technologies that lead to a globally functioning network. Efforts should be made towards international compatibility to achieve this goal.

5. *Define Boundaries*

   Geographical boundaries: Workshop participants suggested for the entire coastal zone to extend out to the Exclusive Economic Zone (EEZ). Working with this boundary will result in several technologies having to overcome related limitations, however, efforts are strongly recommended to reach this specific geographical goal.

   Technological boundaries: Is the focus on above-water, wireless communications? What about cabled systems? Focus on networking technologies, procedures, protocols, and problems with moving data from the sensor to the landside network.

6. Autonomous network functions / sensor platforms. A network could be developed that covered all coastal waters of the US such that a sensor platform could automatically connect to the network, configure itself, and begin communicating data. For example, a network could have transparent integration among shore-based LOS radio and/or satellite communications where an instrument platform or data communications interface would automatically search for the best available carrier. Then this platform (or interface) could connect to a network such as Iridium, GSM/GPRS, or 802.11/16 (also know as WiFi).

7. Leverage commercial technology and then identify niche technology gaps unique to the ocean observing community. Identify the issues lacking interest, resulting in no financial support, to those outside the ocean observing community (i.e., problems that no one else will solve).

8. Define organizations at the state and regional levels instead of in a larger federal forum. Incorporating finances, geography, and politics would help build long term and political plans.

9. Integrate local networks into national operational networks. Using networks that incorporate standard formats would be cost effective because of the already existing database (eg. NOAA's national program).

10. Fund a real study. For example, the National Oceanographic Partnership Program (NOPP) could fund efforts aimed at adopting/adapting wireless technologies for data gathering in the coastal zone. This study would not include instrumentation, rather focus efforts towards pushing forward the telemetry technology.

11. ACT should sponsor a follow-up workshop to facilitate communication from users to manufacturers.

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WORKSHOP PARTICIPANTS

Brenda Leroux Babin
Information Technology Manager
LUMCON (Louisiana Universities Marine Consortium)
8124 Highway 56
Chauvin, LA 70344

Robert (Rob) Bassett
National Oceanic and Atmospheric Administration
(NOAA) Satellites & Information
Program Manager, Polar-orbiting Satellite
(Argos) Data Collection System (DCS)
Federal Office Building 4
Suitland, MD 20746

Melbourne G. Briscoe, Ph.D
Division Director
Office of Naval Research
Ballston Towers One
800 North Quincy Street
Arlington, VA 22217-5660

Darrin Calin
Manager, Technical Support/Field Engineering
Quake Global, Inc.
www.quakeglobal.com
9765 Clairemont Mesa Blvd., Suite A
San Diego, CA 92124

Dale Chayes
Senior Staff Associate
Lamont-Doherty Earth Observatory of Columbia University (LDEO/CU)
PO Box 1000
61 Route 9W
Palisades, NY 10964-1000

Rick Cole
Oceanographic and Diving Operations Manager
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Kevin Delin, PhD
Project Manager, JPL Sensor Webs Project
Jet Propulsion Laboratory
4800 Oak Grove
Pasadena, CA 91109-8099

Jeff Donovan
Systems Administrator
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Rodney Fredericks
Field Projects Coordinator
Louisiana State University
Coastal Studies Institute
E302 Howe-Russell
Baton Rouge, LA 70803

Bill Gibson
Electronics Technician, Research Diver
Louisiana State University
Coastal Studies Institute
Field Support Group BLDG
S. Stadium Dr.
Baton Rouge, LA 70803

Norman L. Guinasso, Jr., Ph.D
Professor, Deputy Director for Ocean Science
Texas A&M University
Geochemical and Environmental Research Group
727 Graham Road
College Station, TX 77845

Sara Haines
Department of Marine Sciences
University of North Carolina
12-7 Venable Hall, CB 3300
Chapel Hill, NC 27599-3300

Robert Heinmiller, Facilitator
Vice President
Omnet, Inc.
21 North Central
Staunton, VA 24401

Thomas O. Herrington, Ph.D
Graduate Professor of Ocean Engineering
Director, NJ Sea Grant Coastal Processes Specialist
Department of Civil, Environmental and Ocean Engineering
Stevens Institute of Technology
Davidson Labs Room 204
711 Hudson Street
Hoboken, NJ 07030

WORKSHOP PARTICIPANTS (CONTINUED)

Jeff Jefferson
Systems Administrator
Baruch Institute
University of South Carolina
Columbia, SC 29208

Jeffrey A. Kinder
Ocean Engineer
Coastal Ocean Science Tech. & Eng. Lab
North Carolina State University
PO Box 8208
Raleigh, NC 27695

Chad Lembke
Project Engineer
Center for Ocean Technology
University of South Florida
College of Marine Science
140 7th Avenue South, MSL 119
St. Petersburg, FL 33705

Peter Lessing
Electronics Engineer and Senior Project Engineer
National Data Buoy Center
1100 Balch Blvd., OPS51
Stennis Space Center, MS 39529

Kevin Locher
President
Locher Environmental Technology
8803 Mt. Royal Lane
Lakeland, FL 33809

Michael Luby, Ph.D
Chief Technology Officer and Co-Founder
Digital Fountain, Inc.
39141 Civic Center Dr., Suite 300
Fremont, CA 94538

Mark Luther, Ph.D, Host
Associate Professor
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Travis McKissack
Project Engineer
Skidaway Institute of Oceanography
10 Ocean Science Circle
Savannah, GA 31411

Scott McLean, Peng
Chief Technology Officer
Vice President Research and Development
Satlantic Incorporated
3481 North Marginal Road
Halifax, Nova Scotia, Canada B3K 5X8

David Meldrum
Leader, Technology Development &
Vice Chairman, Data Buoy Cooperation Panel
Scottish Association for Marine Science
Dunstaffnage Marine Laboratory
Dunbeg, Oban PA37 1QA, Scotland

Cliff Merz, P.E.
Coastal Ocean Monitoring and Prediction System (COMPS) Program Director
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Doug Neff
Applications Engineer
Campbell Scientific, Inc.
815 West 1800 North
Logan, UT 84321

Hien Nguyen, Ph.D
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149-1098

Craig Okuda
Engineer, Research & Development Department
MBARI (Monterey Bay Aquarium Research Institute)
7700 Sandholdt Road
Moss Landing, CA 95039-9644

Workshop Participants (continued)

Mark J. Peebles
Sales Manager
Vaisala Inc.
Sunnyvale Operations
260 Santa Ana Court
Sunnyvale, CA 94085 -4512

Stephen R. Piotrowicz, Ph.D
Deputy Director
Ocean.US
Ocean.US Office
2300 Clarendon Blvd., Suite 1350
Arlington, VA 22201 -3667

Jeff Scudder
Engineer
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Deborah J. Shaw
Director, Department of User Services
Service Argos, Inc.
1801 McCormick Drive, Suite 10
Largo, MD 20774

James Sprenke
Engineer
Center for Oceanographic Products and Services
NOAA N/OPS1
1305 East-West Highway Rm 6535
Silver Spring, MD 20901 -3281

Ron Stanford
Electronics Technician, Research Diver
Louisiana State University
Coastal Studies Institute
E302 Howe-Russell
Baton Rouge, LA 70803

Vembu Subramanian
Data Manager
University of South Florida
College of Marine Science
140 7th Ave South
St. Petersburg, FL 33701

Kenneth R. Tenore, Ph.D
Acting ACT Director
Alliance for Coastal Technologies
Chesapeake Biological Laboratory -UMCES
PO Box 38
Solomons, MD 20688

Eric Terrill, Ph.D
Scripps Institute of Oceanography
Ocean Atmospheric Research Facility
9500 Gilman Drive
La Jolla, CA 92093 -0213

Graham Tilbury
Field Support Engineer
Center for Ocean Technology
University of South Flori da
College of Marine Science
140 7th Avenue South
St. Petersburg, FL 33705

Neil Trenaman
Coastal Sales & Product Manager
RD Instruments
9855 Businesspark Ave
San Diego, CA 92131 -1101

George Voulgaris, Ph.D
Assistant Professor
University of South Caroli na
Marine and Geological Sciences
Columbia, SC 29208

Robert Weisberg, Ph.D
Professor
University of South Florida
College of Marine Science
140 7th Avenue South
St. Petersburg, FL 33701

Paul A. Work, Ph.D., P.E.
Associate Professor
School of Civil and E nvironmental Engineering
Georgia Institute of Technology
6001 Chatham Center Drive, Suite 350
Savannah, GA 31405

Workshop Participants

University of Maryland Technical Report Series No. TS-416-03-CBL

Copies may be obtained from:
ACT Headquarters
c/o University of Maryland Center of Environmental Science
Chesapeake Biological Laboratory
Post Office Box 38
Solomons, Maryland 20688-0038
Email: info@actonline.ws

Appendix D PORTS

COMMUNICATION METHODS - SF PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Golden Gate WL / MET	9414290	IP modem	phone	nothing
Redwood City WL / MET	9414523	IP modem	phone	nothing
Alameda WL / MET	9414750	IP modem	phone	nothing
Oakland MET	9414757	IP modem	phone	nothing
Richmond WL / MET	9414863	IP modem	phone	nothing
Port Chicago WL / MET	9415144	IP modem	phone	nothing
Richmond CURRENTS	S02010	IP modem	nothing	nothing
Oakland CURRENTS	S03020	IP modem	nothing	nothing

COMMUNICATION METHODS - H/G PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Morgans Point WL / MET / CT	8770613	radio	nothing	nothing
Battleship State Park WL	8770743	radio	nothing	nothing
Eagle Point WL /MET /CT	8771013	radio	nothing	nothing
North Jetty WL / MET / CT	8771341	radio	nothing	nothing
Pier 21 WL	8771450	radio	nothing	phone
Pleasure Pier WL / MET	8771510	radio	nothing	phone
Bolivar Roads CURRENTS	g01010	radio	nothing	nothing
Morgans Point CURRENTS	g02010	radio	nothing	nothing

COMMUNICATION METHODS - NY/NJ PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Kings Point WL / MET	8516945	phone	nothing	nothing
The Battery WL	8518750	phone	nothing	nothing
Bayonne Bridge AIR GAP (XPERT)	8519461	IP modem	nothing	nothing
Bayonne Bridge WL / MET / CT	8519483	radio	phone	nothing
Robins Reef MET	8530973	radio/T-1 line	radio/phone	nothing
Sandy Hook WL / MET / CT	8531680	radio/T-1 line	radio/phone	nothing
The Narrows CURRENTS (XPERT)	N03010	radio	nothing	nothing

COMMUNICATION METHODS - TB PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Port Manatee WL / MET	8726384	radio	nothing	nothing
St. Petersburg WL / MET	8726520	radio	phone	nothing
Old Port Tampa WL / MET	8726607	radio	nothing	nothing
Port of Tampa WL / MET	8726667	radio	nothing	nothing
Sunshine Skyway MET	m01010	radio	nothing	nothing
Sunshine Skyway CURRENTS	t01010	radio	nothing	nothing
Old Port Tampa CURRENTS	t02010	radio	nothing	nothing
Port Manatee CURRENTS	t03010	radio	nothing	nothing

COMMUNICATION METHODS - CB PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Reedy Point WL	8551910	radio	phone	nothing
Reedy Point AIR GAP (XPERT)	8551911	IP modem	nothing	nothing
Tolchester Beach WL / MET	8573364	phone	nothing	nothing
Ches. City WL / MET	8573927	radio	phone	nothing
Ches. City AIR GAP (XPERT)	8573928	IP modem	nothing	nothing
Baltimore WL / CT	8574680	IP modem	phone	nothing
FSK Bridge MET (XPERT)	8574728	IP modem	nothing	nothing
Annapolis WL	8575512	phone	nothing	nothing
Cove Point LNG Pier MET (XPERT)	8577018	IP modem	phone	phone
Solomons Island WL / MET	8577330	phone	phone	nothing
Piney Point MET (XPERT)	8578240	IP modem	nothing	nothing
Washington, DC WL (XPERT)	8594900	IP modem	nothing	nothing
Kiptopeke Beach WL /MET (XPERT)	8632200	phone	phone	IP modem
Rapp. Light MET (XPERT)	8632837	IP modem	nothing	nothing
Lewisetta WL /MET	8635750	phone	nothing	nothing
Windmill Point WL (XPERT)	8636580	IP modem	nothing	nothing
York River RR Light MET (XPERT)	8637611	IP modem	nothing	nothing
Yorktown WL / MET / CT (XPERT)	8637689	IP modem	phone	nothing
Dominion Terminal Assoc. MET (XPERT)	8638511	IP modem	nothing	nothing
S. Craney Island MET (XPERT)	8638595	IP modem	nothing	nothing
Sewells Point WL /MET / CT	8638610	phone	phone	nothing
Willoughby Degaussing Station MET (XPERT)	8638614	IP modem	nothing	nothing
CBBT WL / MET / CT (XPERT)	8638863	phone	phone	nothing
Cape Henry MET (XPERT)	8638999	phone	nothing	nothing
Money Point WL / MET / CT (XPERT)	8639348	phone	phone	IP modem
Cape Henry LB 2CH (ATON) CURRENTS	cb0102	IP modem	phone	nothing
Thimble Shoal Ch., LB 18 (ATON) CURRENTS	cb0301	not installed	not installed	not installed
NSN Pier 14 (SL-ADP) CURRENTS	cb0401	IP modem	nothing	nothing
S. Craney Island (SL-ADP) CURRENTS	cb0501	IP modem	nothing	nothing
Newport News, LB 14 (ATON) CURRENTS	cb0601	IP modem	nothing	nothing
York Spit LBB 22 (ATON) CURRENTS	cb0701	not installed	not installed	not installed
Rapp. Shoal LBB 60 (ATON) CURRENTS	cb0801	IP modem	nothing	nothing
Potomac River LWB B (ATON) CURRENTS	cb0901	IP modem	nothing	nothing
Cove Point LNG Pier (SL-ADP) CURRENTS	cb1001	IP modem	nothing	nothing

Ches. Channel LBB 92 (ATON) CURRENTS (XPERT)	cb1101	IP modem	phone	nothing
Tolchester	cb1201	not installed	not installed	not installed
Ches. City (SL-ADP) CURRENTS	cb1301	radio	nothing	nothing

COMMUNICATION METHODS - NB PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Fall River WL / MET / CT	8447386	radio	phone	nothing
Newport WL / MET / CT	8452660	radio	phone	nothing
Conimicut Light WL / MET	8452944	radio	nothing	nothing
Prudence Island MET	8452951	radio	nothing	nothing
Providence WL / MET / CT	8454000	radio	phone	nothing
Quonset Point WL / MET / CT	8454049	radio	nothing	nothing
Fall River CURRENTS (XPERT)	nb0201	radio	nothing	nothing
Quonset Point CURRENTS (XPERT)	nb0301	radio	nothing	nothing

COMMUNICATION METHODS - SOO LOCKS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
De Tour Village WL / MET	9075099	phone	nothing	nothing
Rock Cut WL / MET	9076024	phone	nothing	nothing
Look Out 4 WL	9076028	phone	nothing	nothing
Little Rapids WL / MET	9076032	phone	nothing	nothing
U.S. Slip WL	9076060	phone	nothing	nothing
S.W. Pier WL / MET	9076070	phone	nothing	nothing
Point Iroquois WL / MET	9099004	phone	nothing	nothing

COMMUNICATION METHODS - LA/LB PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Los Angeles (Berth 60) WL	9410660	radio	phone	phone
Gerald Desmond Bridge AIR GAP	9410689	IP modem	nothing	nothing
Pier F MET	m0100	radio	nothing	nothing
Pier S MET	m0101	radio	nothing	nothing
Pier J MET	m0102	radio	nothing	nothing
Pier 400 MET	m0200	radio	nothing	nothing
Badger Ave. Bridge MET	m0201	radio	nothing	nothing
Berth 161 MET	m0202	radio	nothing	nothing
Angels Gate MET	m0203	radio	nothing	nothing

COMMUNICATION METHODS - DB PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Cape May WL / MET	8536110	radio	phone	nothing
Ship John Shoal WL / MET / CT	8537121	radio	nothing	nothing
Tacony-Palmyra WL	8538886	IP modem	nothing	nothing
Burlington WL / MET / CT	8539094	IP modem	nothing	nothing
Marcus Hook WL / CT	8540433	IP modem	nothing	nothing
Philadelphia WL / MET	8545240	radio	phone	nothing
Newbold WL / MET	8548989	IP modem	nothing	nothing
Delaware City WL / MET	8551762	radio	nothing	nothing
Reedy Point WL	8551910	radio	phone	nothing
Brandywine Shoal WL / MET / CT	8555889	radio	nothing	nothing
Lewes WL / MET	8557380	radio	phone	nothing
Brandywine Shoal CURRENTS	db0101	radio	nothing	nothing
Reedy Point CURRENTS	db0201	radio	nothing	nothing
Philadelphia CURRENTS	db0301	IP modem	nothing	nothing
Newbold CURRENTS	db0401	IP modem	nothing	nothing

COMMUNICATION METHODS - NH PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
New Haven WL / MET	8465705	IP modem	Phone	nothing

COMMUNICATION METHODS - TA PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Tacoma WL	9446484	IP modem	phone	nothing
Tacoma MET (XPERT)	9446482	IP modem	IP modem	nothing

COMMUNICATION METHODS - AK PORTS STATIONS

STATION NAME	STATION ID	PRIMARY COMM.	ALT1 COMM.	ALT2 COMM.
Nikiski (XPERT)	9455760	phone	nothing	nothing
Anchorage (XPERT)	9455920	phone	nothing	nothing

Appendix E Technical Workshop on Applications of Iridium Telecommunications to Oceanographic and Polar Research, Universityof Washington, Applied Physics Laboratory

Technical Workshop on Applications of Iridium Telecommunications to Oceanographic and Polar Research, University of Washington, Applied Physics Laboratory

19-21 May 2004
Seattle, WA, U.S.A.

EXECUTIVE SUMMARY

The Technical Workshop on Applications of Iridium Telecommunications to Oceanographic and Polar Research resulted in an unprecedented exchange of information related to the use of Iridium telecommunications in support of a myriad of applications. Attendees outlined the successes, shortfalls, frustrations and lessons learned in implementing Iridium data communications, and participated in Working Groups to analyze information provided and to develop recommendations concerning future actions.

Details relating to "lessons learned" and findings regarding the effectiveness of Iridium data communications in support of specific applications provided during the briefings are included in this document. While the general consensus was that Iridium provides a much needed global data communications capability, findings related to the ease of integration and the success in establishing and maintaining data communications differed widely. One user of a multi-channel Iridium modem reported 39% partial failure rates, while another user reported that the integrated 8-channel system worked "out of the box" and performed better than other data modems. These differences are due, in large part, to dissimilarities in hardware, firmware and supporting software used by Workshop attendees. Many utilized the prototype 9500 data modem. Others used the 9500 or 9505 phones, while some used the enhanced 9505 modem. In addition, a number of users modified the Iridium hardware which may have had an adverse impact on its effectiveness.

The 9505 Iridium phone and data modem incorporates hardware and software upgrades that corrected may of the problems identified during the Workshop. For example, problems associated with the self-initiated internal power-down and Universal

Asynchronous Receiver Transmitter (UART) lock have been identified and corrected. The Data-After-Voice (DAV) capability reduced latency but also contained a bug in the firmware, which has been corrected. Another issue addressed was signal strength fluctuation that could cause the modem to lock up if operating in a continuous mode. This problem was corrected in the 9505 modem, which provides for significant enhancements in both hardware and software over the 9500 prototype version. Newer versions of the NAL Research software allows the user to accurately profile signal strength, addressed as a much needed capability by Workshop participants.

In addition, certain software programs proved more difficult than others to utilize effectively. Several attendees commented that significant problems exist with Kermit that probably contributes to poor transmission success rates. Another attendee noted that a bug in the Linux Point-to-Point protocol daemon (pppd) software caused calls to drop.

While attendees clearly benefited from the exchange of information, it became apparent soon after Workshop discussions began that a more formalized means to capture, compile, document and make available information concerning Iridium data communications is needed. This concept was strongly support by the Working Groups. Questions include, "What works? What doesn't work? What problems exist with particular variants and what "work-arounds" have been identified? Who do we contact?" Issues addressed include the level of support required, how to structure it, who will provide it and who will fund it. Development of a training program was also identified as a critical requirement.

The Workshop was successful in identifying and articulating critical issues related to Iridium telecommunications in support of oceanographic and polar research, and in developing recommendations for consideration. With this accomplished, the task of analyzing and prioritizing requirements and determining future courses of action can be initiated.

Workshop and Its Goals

The Technical Workshop on Applications of Iridium Telecommunications to Oceanographic and Polar Research was conducted at the University of Washington's Applied Physics Laboratory, Seattle, Washington on 19 - 21 May 2004. Sponsored by the National Office for Integrated and Sustained Ocean Observations (Ocean.US) and the Office of Naval Research (ONR), the workshop brought together over 40 leading organizations in oceanographic and polar research and Iridium data communications, including universities, federal laboratories, research institutes, and other organizations worldwide.

During 1998, the National Science Foundation (NSF) sponsored a Small Business Innovative Research Program (SBIR) initiative, the low-Earth Orbit (LEO) Satellite Communications System for NSF Polar Programs, to review satellite data communication options, and to develop a breadboard data modem. The study noted Argos, "has many disadvantages including one-way communications, non-continuous temporal coverage, low data transmission rate, long message latency and high cost due to low volume market." During Phase II of the SBIR, data modem breadboards were developed based on the Iridium and Orbcomm satellite systems. The study recommended further development of a data modem based on the Iridium constellation. During 2002, ONR continued the effort by supporting a SBIR initiative to develop an Iridium data modem prototype based on the 9500 series Iridium RF board. Ninety-six modems were distributed under Phase II of the SBIR, and a number of participants in the Workshop were provided with the 9500 Iridium data modems through the SBIR program for implementation in various applications. In addition, some Workshop participants used the 9500 or 9505 Iridium phone to relay data. How to effectively implement and support the use of the Iridium data communications capability is a focal issue of the Workshop.

The goals of the Workshop included:

- Outlining findings related to the use and effectiveness of Iridium data communication in support oceanographic and polar applications
    - Share hands-on successes and failures, lessons learned, problems, and solutions;

    - Share findings relate to the integration of Iridium data communication hardware/software on specific platforms and systems;
    - Bring together the expertise needed to effectively address issues raised.
- Conduct Working Groups to analyze information provided and issues addressed to develop findings and recommendations concerning future actions to assist users in effectively implementing Iridium data communication;

Briefings provided during the Workshop, a list of participants, and the Technical Workshop agenda can be viewed at http://www.ocean.us/documents/iridium.jsp.

BACKGROUND

Argos Satellite Data Relay System

The most widely used satellite data relay system for scientific research remains Argos. Traditionally, communication is one-way only, at 400 baud, with practicable data rates of the order of 1 kbyte per day. Transmissions 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 now, Argos has flown as an attached payload on the NOAA Television and Infrared Observation Satellite (TIROS) weather satellites, but the recent launch on board the Japanese Advanced Earth Orbiting Satellite (ADEOS-II) vehicle and projected launches on board the European Meteorological Operational Satellite (METOP) platforms mark an important diversification of service provision.

Enhancements to the Argos on board equipment (‘Argos-2’) include increased receiver bandwidth and sensitivity, with a highly significant move to two-way communication (‘downlink messaging’) which was piloted aboard the short-lived ADEOS-II, launched in December 2002. It was equipped with two Japan Aerospace Exploration Agency (JAXA) sensors: Advanced Microwave Scanning Radiometer (AMSR) for quantitatively observing various geophysical data concerning the water cycle, and Global Imager (GLI) for observing oceans, land and clouds with high accuracy. Next generation Argos equipment (‘Argos 3’) will fly from 2006 onwards on board METOP-1, and will offer order of magnitude increases in data rates, as well as two-way communications.

Argos is one of the few systems that offers true global coverage. The first of the Argos-2 satellites was launched in May 1998, and has been followed in September 2000 by NOAA-L (NOAA-16), and by NOAA-M (NOAA17) in June 2002. New direct readout stations continue to be commissioned bringing the current total to more than 40. Recent additions included stations in the Antarctic Peninsula (Chile, Meteo Chile), Athens (Greece, CLS), Fiji (Fiji, FMS), Punta Arenas (Chile), Ryad (Saudi Arabia, CACST), Söndre Stromfjord (Greenland, DMI) and Tromsö (Norway, NMI). This continues the programme of improving data timeliness by exploiting use of Argos in 'bent-pipe' mode.

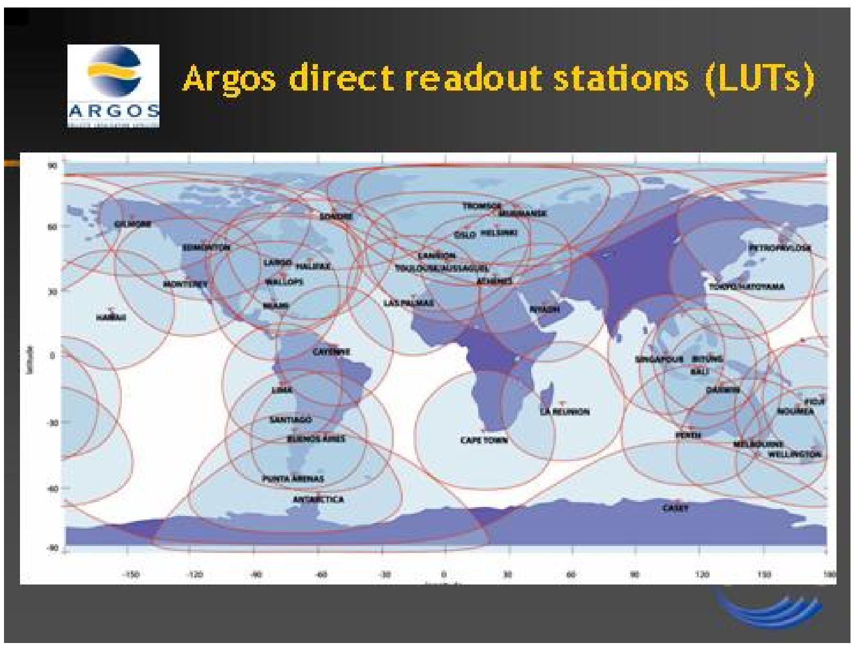


Figure 1: ARGOS Direct Readout Stations (LUTs)

Data collection platforms that utilize the Argos system for meteorological and oceanographic purposes include drifting buoys, ice buoys, moored buoys, sub-surface floats, ships, containers, balloons, Automatic Weather Stations (AWSs) and animals. The Argos system is comprised of Platform Transmitter Terminals (PTTs), the space segment and the ground segment. A PTT includes an antenna, a RF modulator, a power amplifier, a sensor interface unit, an ultra-stable oscillator and a power supply. PTTs are attached to sensor equipment, platforms and even on migratory birds from which data are collected. They are configured by size, weight, power consumption and housing according to the application. An Argos PTT uplinks messages to the satellite at a nominal frequency of 401.65MHz that may contain up to 225 bits (out of 256 bits) of sensor data per message. During a satellite overpass, each PTT can normally transmit at an Argos assigned repetitive period ranging from 40 to 240 seconds. The average duration of PTT visibility by the satellite or the "window" during which the satellite can receive messages from the PTT is about 10 minutes for each satellite pass, assuming that the satellite must be at least 5^{o} above the horizon. Up to four simultaneous PTT messages can be acquired by an Argos satellite provided that they are separated in frequency.

The satellites pass the poles at greater frequency than at the equator. Regardless, for successful transmission of data messages, the schedule of satellite overpass must be accurately provided to the PTT. For example, a contour plots of cumulative visibility time of the NOAA-12 and NOAA-14 over a 24-hour period assuming that the line-of-sight to the satellites is 5^{o} above the horizon. This plot shows that NOAA-12 and NOAA-14 satellites provide slightly less than 5 hours of coverage over the polar regions and approximately 1.5 hours around equatorial regions each day. Since PTTs are required to uplink at an assigned repetitive period, less than 2% of the total satellite visibility time.

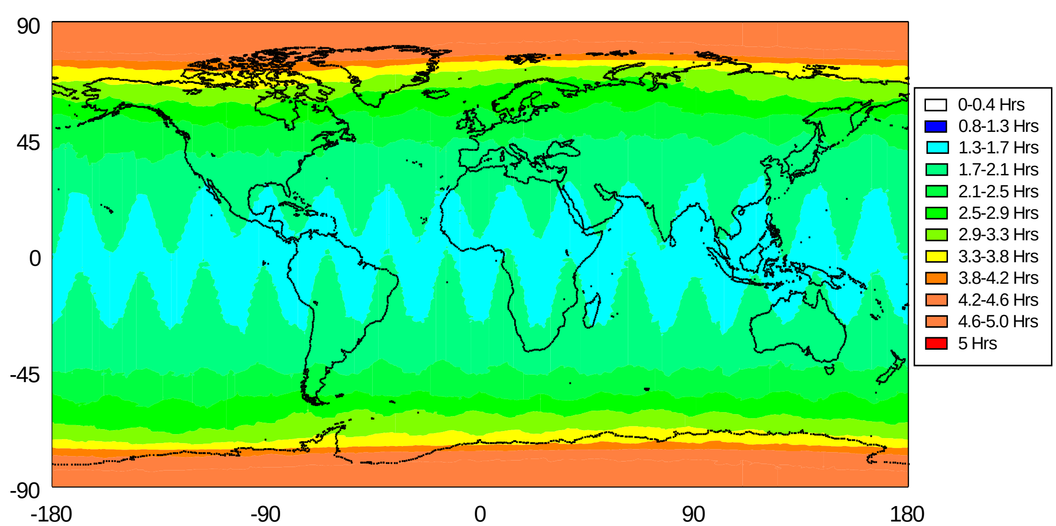


Figure 2: ARGOS Data Latency

can be used for transmission. Moreover, data are frequently retransmitted multiple times for each satellite overpass to improve position prediction and to ensure data integrity, which further reduces the overall system capability.

Data are immediately down linked in real-time if the satellite is in view of a ground station or stored on tape for later downlink. For the latter case, data recorded on tape are read out and transmitted to the ground each time the satellite passes over one of the telemetry stations. Argos data are then rebroadcast from the telemetry ground stations through telecommunication satellites to the National Environmental Satellite Data and Information Service (NESDIS)/NOAA computer facility. The data are demodulated and forwarded to Argos Data Processing Centers. At the Argos Data Processing Centers, PTT transmitter locations and sensor data are interpreted and the results are made available to the users. Data maybe obtained by users from tapes, floppy disks, computer printouts or computer files accessible by the Internet, telephone, telex or other communication networks. Most data are available within four hours (Figure 3) after the receipt of data rebroadcast from the satellites. The Argos Data Processing Centers receive PTT messages in near real-time when both a regional ground station and a PTT are simultaneously in view of a satellite during transmission.

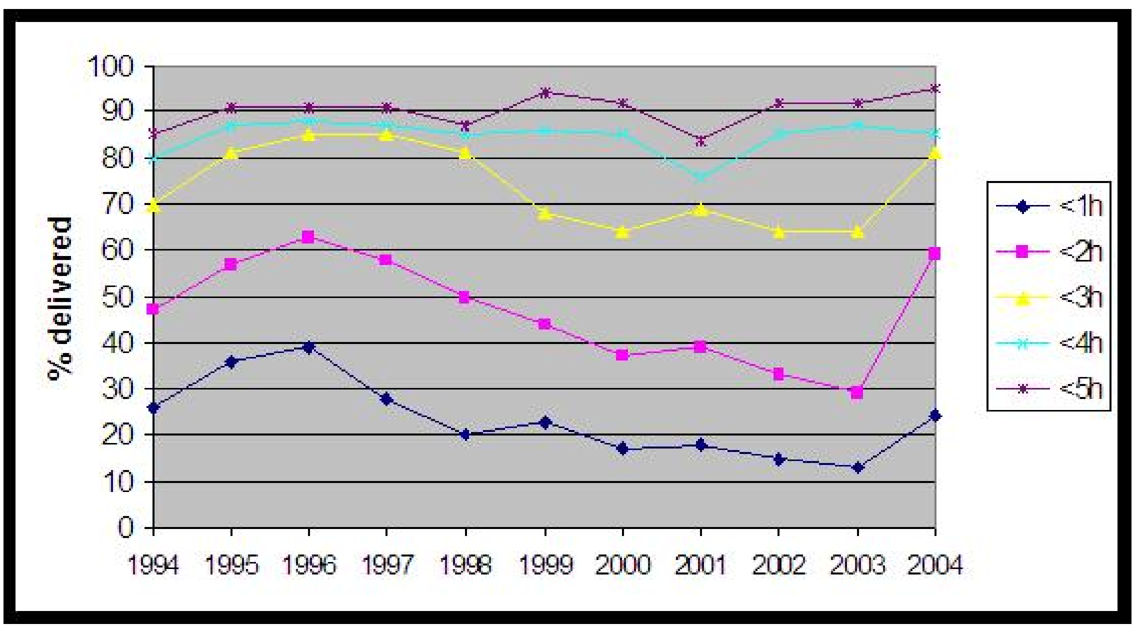


Figure 3: ARGOS Data Timeliness

Iridium Satellite System Overview

The Iridium system is the only satellite system that provides true global coverage, to include all ocean areas and Polar Regions, at all times. It provides a two-way, near-real time data communications capability as all areas of the earth are covered with at least one satellite. The Iridium system is a low-Earth orbit (LEO) satellite network developed by Motorola® to provide personal mobile services. The original concept was visualized as far back as 1987 and was granted a full FCC license in January of 1995 for construction and operation in the United States. The Iridium satellite network is now owned and operated by Iridium Satellite LLC (ISLLC). There are four components to the network: (1) a constellation of 66 satellites and 13 spares, (2) three terrestrial gateways, (3) a Satellite Network Operations Center (SNOC) and (4) Iridium Subscriber Units (ISU).

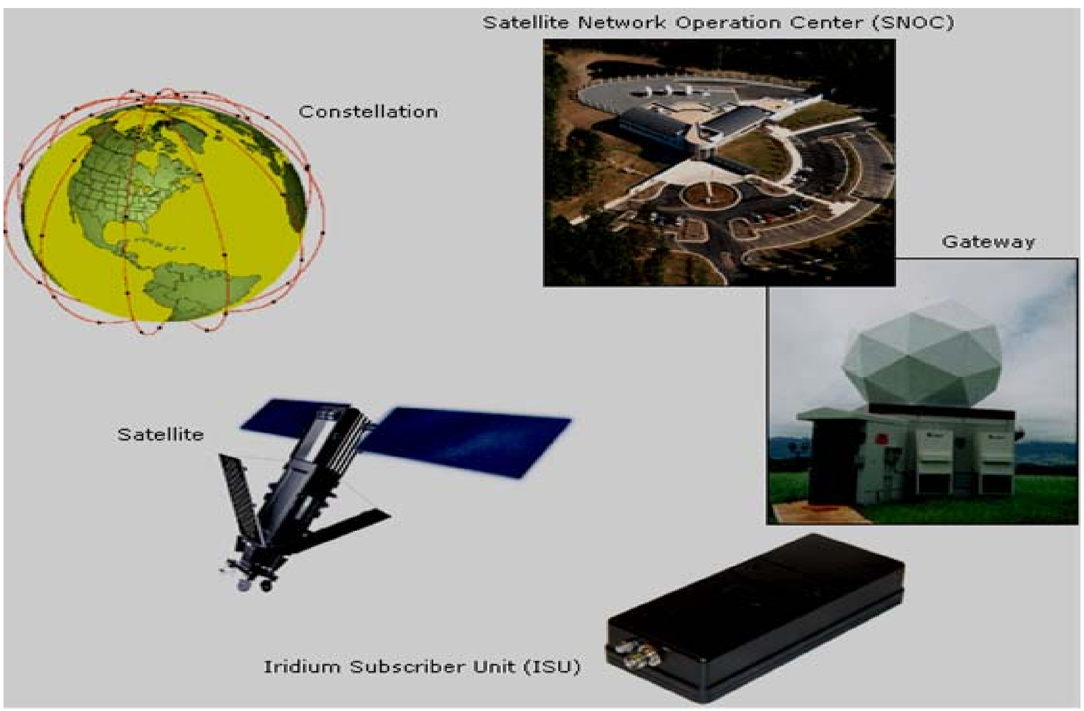


Figure 4: Iridium Satellite System

Please see http://www.nalresearch.com/QuickRef_NetworkDescription.html for a video showing the orbit of the Iridium satellites.

Each Iridium satellite is ~4 meters high and weighs ~667 kg fully fueled. Each satellite has three L-band antenna panels providing the 48 beams of footprint. The satellite has four 23 GHz cross-links antennas. These antennas point to the nearest spacecraft in the same plane (fore and aft) and in the two adjacent co-rotating planes. The "feeder link" antennas relay information to the terrestrial gateways. The spacecraft payload is the dominant component with high-speed digital switching to handle complex telephony routing.

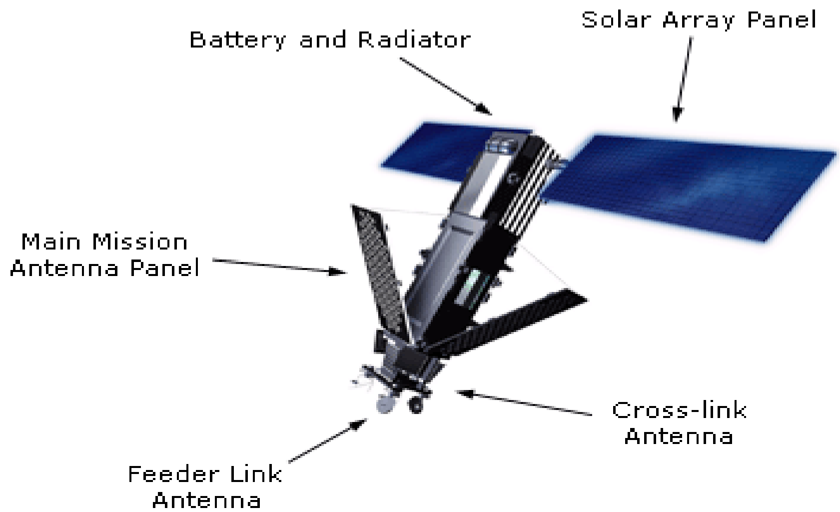


Figure 5: Iridium Satellite

The satellites are in 6 orbital planes separated by 31.6^{o} at an altitude of 780 km and 86.4^{o} inclination. The Iridium network is designed to operate in the L-band of 1616 to 1626.5 MHz for ground user links, in the Ka-band of 19.4 to 19.6 GHz and 29.1 to 29.3 GHz for gateway down- and up-links and in the Ka-band of 23.18 to 23.38 GHz for Inter-Satellite Links (ISL). The exact L-band frequencies used depend on local regulating authorities and issued licenses in any particular region.

Each satellite projects 48 spot beams on the surface of the Earth, which may be viewed as providing coverage cells on the ground similar to terrestrial cellular systems. Each beam is approximately 600 km in diameter. The 66-satellite constellation has the potential to support a total of 3,168 spot beams; however, as the satellite orbits converge at the poles, overlapping beams are shut down to prevent interferences. The satellite footprint is ~4,700 km in diameter. Under each footprint, a satellite's power is limited to ~1,100 simultaneous circuits. A user is in view of a satellite for approximately 9 minutes, with about 1 minute under each beam, before being handed-off to the next satellite.

Inter-satellite link or ISL is the network architecture employed by Iridium (versus bent-pipe employed by Globalstar and Orbcomm). A unique feature of the Iridium ISL capability is that the satellites not only can talk to ISU and gateways, but they can also talk to each other, forming a network aloft. When a signal is up-linked to a satellite by an ISU, it is down-linked immediately to a gateway located within the satellite's footprint and then gets distributed to the final destination. However, when a gateway is not visible to the satellite, information is passed through the network of satellites to the one that is immediately over a gateway. Iridium ISL also allows ISUs to talk to each other without ever referencing to any ground stations at all thereby reducing signal latency that can adversely affect time-sensitive protocols such as TCP/IP.

ISL provides benefits such as enhanced system reliability and capacity and reduces the number of gateways required. The greatest advantage of using ISL is essentially the capability of truly worldwide coverage without signal latency in either voice or data mode. By eliminating the dependency on ground infrastructure for traffic links, an ISL-based system such as Iridium becomes more autonomous. Moreover, ISL can make communications virtually impervious to terrestrial service disruptions that may be caused by earthquakes, hurricanes, floods and other natural and man-made causes.

There are currently two commercial Iridium gateways located in Tempe, Arizona, United States and Fucino, Italy. The U.S. government/Department of Defense (DoD) selected Iridium for voice and data communications due, in large part, to its global coverage and secure systems architecture. The U.S. government owns and operates a secure Iridium gateway located in Hawaii. Each gateway generates and controls all user information pertaining to its registered users, such as user identity, geo-location and billing items. Gateways also provide connectivity from the Iridium system to the terrestrial based networks such as the PSTN (Public Switched Telephone Network), DSN (Defense Switched Network), Internet, Misprint, etc. Although there are multiple gateways, a user is registered to a single gateway that will handle his data and voice communications.

An Iridium Subscriber Unit or ISU can either be an Iridium satellite phone or any of Iridium's CDM and 9500/9505 series modems. It is capable of operating from 1616.0 to 1626.5 MHz; however, the actual frequencies used are in accordance with regional spectral licenses and international frequency coordination. An ISU (as well as Iridium satellites) uses Right Hand Circular Polarization (RHCP) and provides a maximum gain of 3.5 dBic from 8.2° to 90° elevation and a maximum gain of 0 dBic at 0° elevation. The average and peak RF transmitted powers are 0.6W and 7W, respectively.

The L-band interface between an ISU and an Iridium satellite is based on hybrid FDMA/TDMA (Frequency Division Multiple Access/Time Division Multiple Access) architecture using a 90 milli-second frame TDD (Time Division Duplex). The fundamental unit of the TDMA channel is a time-slot, which is organized into frames. A frame consists of a 20.32 milli-second downlink simplex time-slot, followed by four 8.2 milli-second uplink time-slots and four downlink time-slots with various guard times interspersed. Each frame is composed of 2250 symbols at the channel burst modulation rate of 25 kilo symbols per second (ksps).

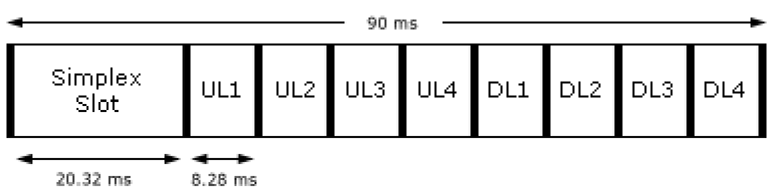


Figure 6: Iridium L-Band Interface Structure

Frequency accesses are divided into the duplex channel band and the simplex channel band. The duplex channel band is further divided into sub-bands, each occupies 333.333 kHz. In duplex operation, the Iridium network is capable of operating up to 30 sub-bands, containing a total of 240 frequency accesses. The Iridium system re-uses duplex channels from beam to beam when sufficient spatial isolation exists to avoid interference. A 12-frequency access band is reserved for the simplex channels. These channels are allocated in a globally allocated 500 kHz band between 1626.0 to 1626.5 MHz.

The L-band downlink channels use DE-QPSK (Differentially Encoded Quaternary Phase Shift Keying) for traffic, broadcast, synchronization, ring alert and messaging. Power

Spectral Flux Density (PSFD) provided to ISU ensures adequate service link margins. The uplink traffic channels use DE-QPSK modulation. The uplink acquisition and synchronization channels both use DE-BPSK (Differential Encoded Binary Phase Shift Keying). BPSK is used since it provides a 3 decibel (dB) link advantage, which improves the burst acquisition probability. Traffic channels operate with adaptive power control, which acts to limit power transmissions beyond what is required for a robust connection.

The L-band link between an ISU and Iridium satellite is designed for a threshold channel bit error of 0.02. The system operates with an average link margin of 13.1 dB above this level. Under good channel conditions, this level is reduced by adaptive power control. Even under adaptive power control, link margin is maintained to mitigate fades that are too short in duration to be compensated for by the power control loop. Adaptive power control uses a closed loop algorithm to adjust their transmitted power to the minimum value necessary to maintain high link quality. When the entire available link margin is not required to mitigate channel conditions, adaptive power control has the effect of reducing system power consumption.

The Iridium network makes calculations of the geographical location (geo-location) of an ISU each time a call is placed. This is done for billing purposes only. The technique employed to determine the geo-location of an ISU is based on measurements of the ISU and satellite propagation delay and Doppler frequency shift. These measurements are used to estimate cosines of spherical angles that identify the ISU's location relative to the satellite by the gateway. In the Iridium geo-location process, the ISU sends the satellite an uplink geo-location burst, saving the delay and Doppler corrections needed to send the message. When the satellite receives the uplink geo-location burst from the ISU, it measures the time and frequency offsets of the burst relative to its time and frequency standards. The satellite then responds with a downlink burst, which the ISU uses as an acknowledgement that the satellite has received the previous uplink geo-location burst. When the downlink burst arrives, the ISU checks to see if it is satisfied with its estimates for the timing and Doppler. If so, it then transmits an uplink ACCHL message to the satellite that includes the propagation time and Doppler frequency offsets that were used by the ISU during the last geo-location uplink burst. If the ISU did not receive a response, or if the ISU is not satisfied with the accuracy of the exchange, the ISU will repeat the process again.

The Iridium network can locate an ISU to within 10 km only about 78% of the time. The location accuracy can be much higher; however, the information is not available to commercial users. Geo-location errors in the east-west dimension, therefore, are sometimes more than 100 times greater than in the north-south dimension. However, DoD sponsored the development of the Iridium modem with integrated GPS module to provide accurate location data independent of geo-positioning.

The Iridium network supports Global System for Mobile Communications (GSM)-based algorithms for authentication and encryption to safeguard critical data to the satellites.

INMARSAT Satellite System Overview

The Inmarsat Satellite System is supported by a constellation of geostationary satellites that extend mobile phone, fax and data communications to every part of the world, except the poles and selected ocean areas. The satellites are controlled from Inmarsat's headquarters in London, which is also home to Inmarsat Group Holdings Ltd, Inmarsat's parent company, as well as a small InterGovernmental Organization (IGO), the International Mobile Satellite Organization (IMSO), created to supervise the company's public-service duties to support the Global Maritime Distress and Safety System (GMDSS) and satellite-aided air traffic control for the aviation community.

Inmarsat came into being to provide global safety and other communications for the maritime community. Starting with a customer base of 900 ships in the early 1980s, it then grew rapidly to offer similar services to other users on land and in the air until, in 1999, it became the first IGO to be transformed into a private company. It now supports links for phone, fax and data communications to ship, vehicle, aircraft and other mobile users.

Inmarsat's primary satellite constellation consists of four Inmarsat (I-3) satellites in geostationary orbit. These are currently backed up by a fifth spacecraft that can be brought in to provide additional capacity. Between them, the main "global" beams of the satellites provide overlapping coverage of the surface of the Earth apart from the Polar Regions and selected ocean areas.

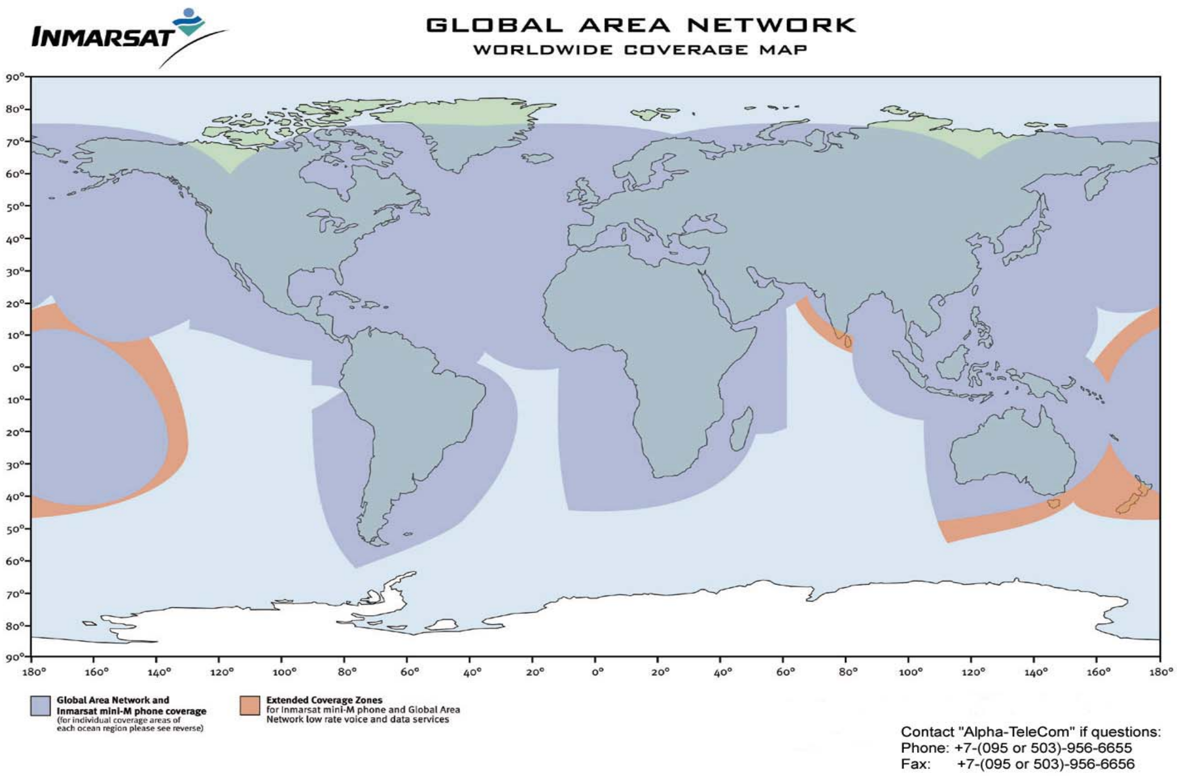


Figure 7: INMARSAT COVERAGE

A geostationary satellite follows a circular orbit in the plane of the Equator at a height of 35,600 km, so that it appears to hover over a chosen point on the Earth's surface. Three such satellites are enough to cover much of the Earth's surface.

The control teams at the Satellite Control Center (SSC) in London are responsible for keeping the satellites in position above the Equator, and for ensuring that the onboard systems are fully functional at all times. Data on the status of the nine Inmarsat satellites is supplied to the SCC by four tracking, telemetry and control (TT&C) stations located at Fucino, Italy; Beijing, China; Lake Cowichan, western Canada; and Pennant Point, eastern Canada. There is also a back-up station at Eik in Norway.

A call from an Inmarsat mobile terminal goes directly to the satellite overhead, which routes it back down to a gateway on the ground called a Land Earth Station (LES). From there the call is passed into the public phone network. The Inmarsat I-3 satellites are supported by four previous-generation Inmarsat-2s, also in geostationary orbit. A key advantage of the Inmarsat I-3s over their predecessors is their ability to generate a number of spotbeams as well as single large global beams. Spotbeams concentrate extra power in areas of high demand, as well as making it possible to supply standard services to smaller, simpler terminals.

Launched in the early 1990s, the four second-generation Inmarsat I-2 satellites were built to Inmarsat specification by an international group headed by British Aerospace (now BAE Systems). The three-axis-stabilized Inmarsat I-2s were designed for a 10-year life. Inmarsat-2 F1 was launched in 1990 and is now located over the Pacific, providing lease capacity. F2, launched in 1991, is over the western Atlantic, providing leased capacity and backing up Inmarsat I-3 F4. Also orbited in 1991, F3 is stationed over the Pacific Ocean, providing lease capacity and backing up Inmarsat I-3 F3. The fourth Inmarsat-2 was launched in 1992 and is used to provide leased capacity over the Indian Ocean and backing up Inmarsat I-3 F1 and Inmarsat I-3 F3.

Launched in 1996-8, the Inmarsat I-3s were built by Lockheed Martin Astro Space (now Lockheed Martin Missiles & Space) of the USA, responsible for the basic spacecraft, and the European Matra Marconi Space (now Astrium), which developed the communications payload. The Inmarsat I-3 communications payload can generate a global beam and a maximum of seven spotbeams. The spotbeams are directed as required to make extra communications capacity available in areas where demand from users is high. Inmarsat I-3 F1 was launched in 1996 to cover the Indian Ocean Region. Over the next two years F2 entered service over Atlantic Ocean Region-East, followed by F3 (Pacific Ocean Region), F4 (Atlantic Ocean Region-West) and F5 (limited services on a single spot beam, back-up and leased capacity).

Responding to the growing demand from corporate mobile satellite users for high-speed Internet access and multimedia connectivity, Inmarsat has been building its fourth generation of satellites. The company awarded European spacecraft manufacturer Astrium the contract to build the three Inmarsat I-4 satellites. The job of the satellites will be to support the new Broadband Global Area Network (BGAN), currently scheduled to enter service in 2005 to deliver Internet and intranet content and solutions, video-on-demand, videoconferencing, fax, e-mail, phone and LAN access at speeds up to 432kbit/s almost anywhere in the world. BGAN will also be compatible with third-generation (3G) cellular systems. The satellites, the world's largest commercial communications satellites, will be 100 times more powerful than the present generation and BGAN will provide at least 10 times as much communications capacity as today's Inmarsat network.

IRIDIUM AND OCEAN OBSERVATIONS

Why did the ONR choose to develop the Iridium data modem under a Small Business Innovative Research Program initiative?

The Iridium Satellite System is the only provider of truly global, truly mobile satellite voice and data solutions with complete coverage of the Earth (including oceans, airways and Polar regions). Iridium provides benefits such as enhanced system reliability and capacity; it eliminates the need for multiple regional gateways, reducing associated costs and eliminating a potential regional "single point of failure." In addition, ISL allows the capability of global coverage without signal latency in either voice or data mode.

Figure 8: Iridium Satellite Constellation

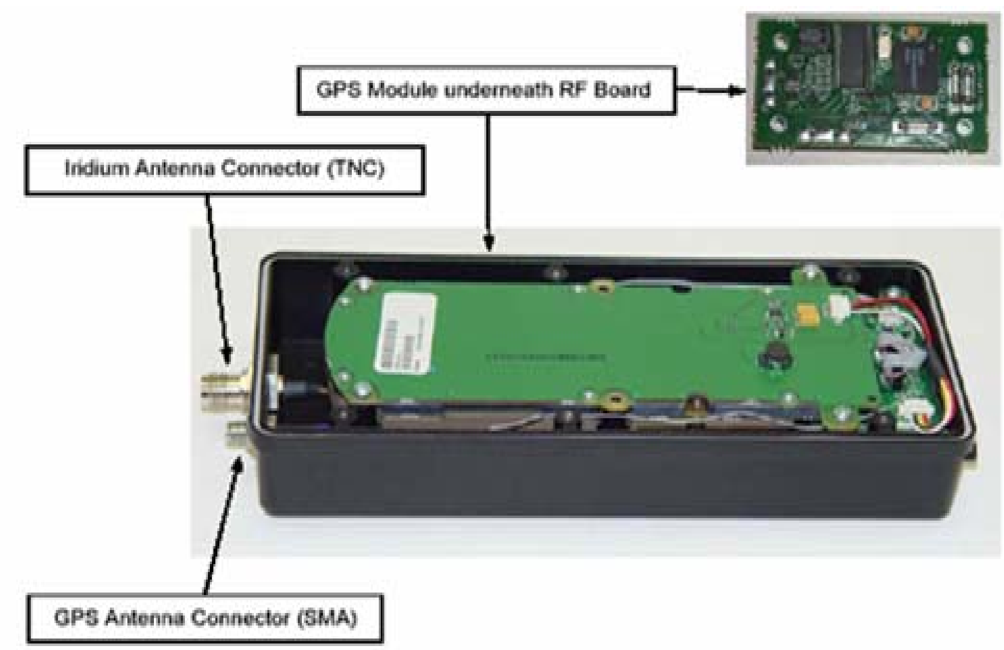
The Iridium constellation consists of 66 operational satellites and 13 spares orbiting in a constellation of six polar planes. Each satellite is cross-linked to four other satellites; two satellites in the same orbital plane and two in an adjacent plane.

Iridium provides a greater data throughput capacity than Argos without the associated latency. As addressed above, in the Argos system, data is often stored on tape for later downlink with latency timeframes as previously addressed above. Iridium covers areas not serviced by Globalstar or Orbcomm. In addition, as Iridium satellites orbit at 780km above earth, considerably less power is required to relay data as compared to the GEO Inmarsat system, positioned 33,600km above the earth. . For many of these reasons, the DoD entered into a series of telecommunications service contracts with Iridium through 2008, and developed a DoD owned and operated gateway in Hawaii.

In addition, there are now a variety of Iridium data communications capabilities to support the user specific requirements. Information on dial-up, direct internet, Router-based Unstructured Digital Inter-Working Connectivity Solution (RUDICS), Short Burst Data (SBD) and Short Messaging Service (SMS) were addressed by Iridium Satellite LLC during the workshop. Please see the brief by Scott Scheimreif and Kent Keeter (Iridium Satellite LLC) at http://www.ocean.us/documents/iridium.jsp for additional information.

The silver 9500 Iridium data modem was the first version modem developed under the ONR SBIR initiative and was distributed to many workshop participants. The 9505 modem followed with significantly enhanced hardware and firmware. Finally, the Iridium data modem with integrated GPS module and micro-controller was developed.

9500 Iridium Data Modem **9505 Iridium Data Modem**



9505 Iridium Data Modem with GPS

Figure 9: Iridium Data Modems and Modem with GPS

WORKSHOP REPORT; IRIDIUM APPLICATIONS AND FIELD RESULTS; MOBLIE APPLICATIONS, HIGH LATITUDE APPLICATIONS AND FIXED PLATFORM WORKING GROUP FINDINGS

The following briefings, summarized below, are available on the Ocean.US web site, http://www.ocean.us/documents/iridium.jsp, were presented:

Supplemental Contribution: Overview, Performance and Reliability from Summer 2004 SUMMIT, Greenland Field Experiments July 14-July 25, 2004 - Abdul Jabbar Mohammad, Said Zaghloul, Victor Frost, and Dan F. Servey (University of Kansas)

A 24x7 9600 baud Continuous Mobile to Mobile Connection for Network to Network Connectivity - Gary L. Ferentchak (Raytheon Polar Services)

Using Iridium to Transmit Geodetic GPS Data from Remote Antarctic Installations - Paul Tregoning (Australian National University)

Experiences with an Iridium Based Communications System in Polar Regions - Victor Frost (University of Kansas)

Polar Experience with Iridium:Dial-up and SBD - David Meldrum and Duncan Mercer (Scottish Association of Marine Sciences)

Experiences with Real-time Data Retrieval from Remote Observatories using Iridium Communications Links - Dan Detrick (University of Maryland)

Iridium Data Transfer from North Pole Deployed Ocean Flux Buoys - Tim Stanton (U.S. Naval Postgraduate School)

Communications in Rapid Environmental Assessment - Alex Trangeled (NATO SACLANT Center)

Experiences with Real-Time Data Retrieval from Remote Stations using Iridium; and Data Distribution: GTS and IOOS - Steve Collins (U.S. National Data Buoy Center)

Seaglider Communications Performance: Results from Two Years of Open Ocean Operations - Neil Bogue and James Bennett (University of Washington)

ARGO, Profiling Floats, and Iridium - Stephen C. Riser and Dana Swift (University of Washington)

First Experiences with an Iridium Telemetry System on the DOLAN Buoy in the Atlantic - Eberhard Kopiske (University of Bremen)

An Overview of PMEL Iridium Ocean Observatories - Christian Meining (Pacific Marine Environmental Laboratory

Real-time Over-the-horizon Communications for MBARI's Ocean Observing System
AOSN II - AOSN II Video - Lance McBride (Monterey Bay Aquarium Research Institute)

Gulf of Maine Ocean Observing System (GoMOOS) - Robert Stessel (University of Maine)

Experiences with a Small Moored Surface Telemetry Buoy Including the Subsurface Inductive Data Link - Andreas Pinck (Institute für Meereskunde, Universität Kiel)

Use of Iridium in a Small Moored Buoy, and on a Large Commercial Vessel - Jonathan Campbell (Southampton Oceanography Center)

Iridium Enabled TCP/IP for Coastal Ocean Observing Systems - Christopher Calloway (University of North Carolina)

Iridium Satellite LLC, System Update - Scott Scheimreif and Kent Keeter (Iridium Satellite LLC)

Workshop participants are identified below.

Technical Workshop on Applications of Iridium Telecommunications Participants

Name	Affiliation	Email Address
David Meldrum	Scottish Association for Marine Science	David.meldrum@sams.ac.uk
Tim Stanton	U.S. Naval Postgraduate School	stanton@nps.navy.mil
Paul Tregoning	Australian National University	pault@rses.anu.edu.au
Victor Frost	University of Kansas	frost@ittc.ku.edu
Scott Scheimreif	Iridium Satellite LLC	Scott.Scheimreif@iridium.com
Pat McLain	Pacific Marine Environmental Laboratory	patrick.d.mclain@noaa.gov
Gary Ferentchak	Raytheon Polar Services	Gary.Ferentchak@usap.gov
Robert Vehorn	U.S. Navy Space Warfare Systems Center	robert.vehorn@navy.mil
Scott Stalin	Pacific Marine Environmental Laboratory	scott.e.stalin@noaa.gov
Lance McBride	Monterey Bay Aquarium Research Institute	lance@mbari.org
Christian Meinig	Pacific Marine Environmental Laboratory	christian.meinig@noaa.gov
Steve Collins	NOAA/National Data Buoy Center	Steve.Collins@noaa.gov
Nan Galbraith	Woods Hole Oceanographic Institution	ngalbraith@whoi.edu
Robert Stessel	University of Maine	stessel@maine.edu
Jeff Kinder	North Carolina State University	jakinder@ncsu.edu
Eberhard Kopiske	University of Bremen	Ekopiske@marum.de
Christopher Calloway	University of North Carolina	cbc@unc.edu
Songnian Jiang	University of California Santa Barbara	Songnian.Jiang@opl.ucsb.edu
Russell.L.Richards	Pacific Marine Environmental Laboratory	russell.l.richards@noaa.gov
Steve Ackleson	U.S. Office of Naval Research	ackless@onr.navy.mil
Robert Bassett	NOAA/NEDIS	robert.bassett@noaa.gov
Stephen R. Piotrowicz	Ocean.US/NOAA	steve.piotrowicz@noaa.gov

Jonathan Campbell	Southampton Oceanography Center, United Kingdom	joc@soc.soton.ac.uk
Charles Eriksen	University of Washington Department of Oceanography	eriksen@u.washington.edu
Andreas Pinck	Institute für Meereskunde, Universität Kiel	apinck@ifm.uni-kiel.de
Gerard Loaec	French Research Institute for Exploration of the Sea	gerard.loaec@ifremer.fr
Steve Riser	University of Washington Department of Oceanography	riser@ocean.washington.edu
Alex Trangeled	NATO SACLANT Center, La Spezia	alex.trangeled@poste.it
Duncan Mercer	Scottish Association for Marine Science	duncan.mercer@sams.ac.uk
Dan Detrick	University of Maryland	detrick@uarc.umd.edu
Dana Swift	University of Washington Department of Oceanography	swift@ocean.washington.edu
Ngoc Hoang	NAL Research	nth@nalresearch.com
Neil Bogue	University of Washington Department of Oceanography	bogue@u.washington.edu
James Bennett	University of Washington Department of Oceanography	jsb11@u.washington.edu
Raymond Steedman	University of Western Australia	steedman@cwr.uwa.edu.au
William Hansen	NOAA/National Data Buoy Center	bill.hansen.contractor@noaa.gc
Kent Keeter	Iridium Satellite LLC	kent.keeter@iridium.com
Robert Anderson	Applied Physics Lab, Univeristy of Washingrton	Robert.M.Anderson@saic.com
Timothy Wen	Applied Physics Lab, Univeristy of Washingrton	Tim@apl.washington.edu
Rick Anderson	NAL Research	Rick_Anderson@nalresearch.c

Following the briefings, attendees were divided into Working Groups, to focus on issues related to mobile, fixed and high latitude applications. Working Group finding are addressed later in the proceeding.

Overview of briefings presented follows:

United States Antarctic Program, Supervisory Control of Iridium LBTs for Continuous Multi-Channel ML-PPP Applications, Gary Ferentchak, Raytheon Polar Services

- NSF tasking to utilize multi-channel (four) modems to provide continuous network to network link between the South Pole and Denver
  - Modems (ISU to ISU) were used with a Cisco 2651 Router with ASYNC card
  - DoD and commercial SIM cards used
- Information on the frequency of dropped calls
  - Average drop for Denver to Denver calls ranged from 2 hours and 2 minutes during night and weekends to 30 to 40 minutes during prime business hours

- Average drop for Denver to South Pole ranged from 20 to 25 minutes on good days to 10 - 20 minutes on bad ones, although it did "clear up some" later on
  - Help provided by Iridium and Boeing in moving the RTAD from McMurdo Station to South Pole
  - Early testing showed 13.8 drops per channel per 24 hours
  - Noted non-responsive units
- Issues/Problems
  - Self-initiated Internal Power-Down (DAV) (95%)
  - UART Lock-up (4%)
  - Occasional Failure to present DSR (less than 1%)
  - Continuously working with Boeing and NAL Research
  - CISCO router successfully recovers responsive LBTs and reestablishes the recovered channel into the ML-PPP session - all the while managing data flow through the remaining channels - if the LBTs are responsive!
  - Noted a requirement to be able to profile signal strength and to correct self-initiated power-down
- Attendees identified that many problems noted have been corrected
  - John Rice from Iridium stated that the problem causing power-down and UART lock had been determined and corrected
  - Dr Hoang from NAL Research noted software is now available to profile signal strength
  - The 9505 modem and modem with GPS provides a more robust and consistent capability than the 9500 modems

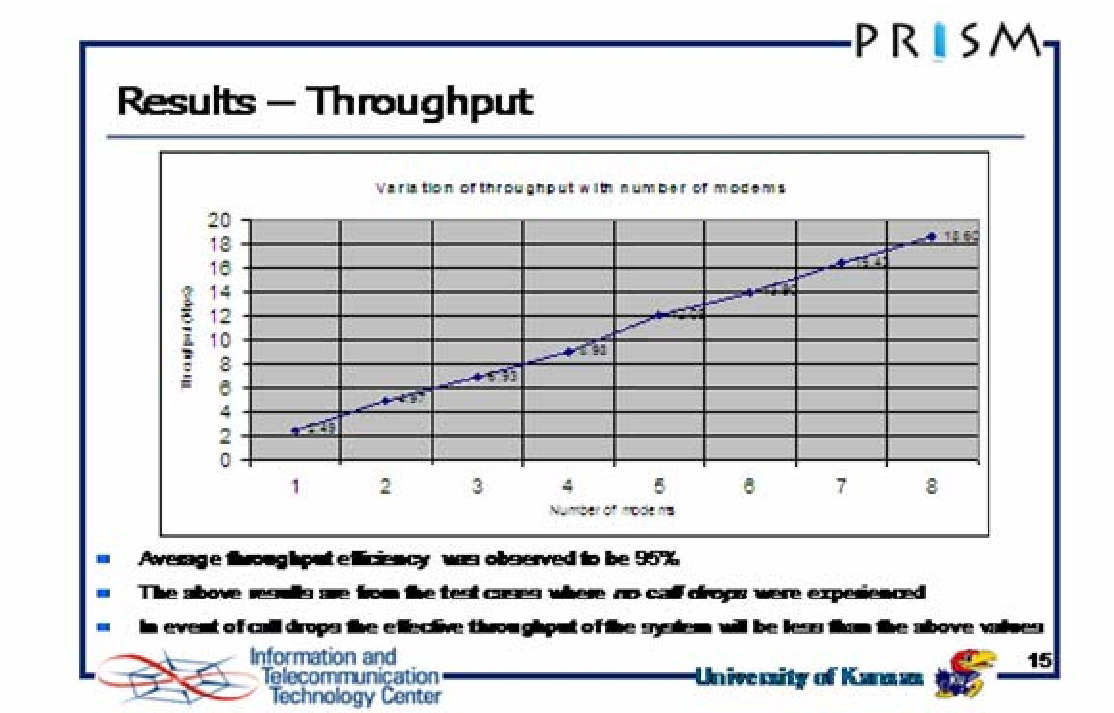
Transmitting GPS data from Remote Installations in Antarctica Using the Iridium System, Paul Tregoning, Research School of Earth Sciences, The Australian National University Canberra, ACT Australia

- The goal was to measure the rate of present-day rebound of the Antarctic continent
  - Amount and timing of melting of ice sheet
  - Implications for present-day global sea-level change
  - 4 sites installed - visited once a year - solar powered - full automated
    - 2 with Inmarsat-B
    - 2 with Iridium
  - Inmarsat is expensive, difficult to install, high power consumption, 9600 baud, high success rate of transmission
  - Iridium is less expensive, small and easy to install, low-power requirement, 2400 baud, variable success rate of data transmission
- Transfer process
  - TP400 computer running Linux
  - Data transfer using the program "Kermit"
  - Dialup system to connect to a computer in Canberra running Unix
  - Transfer of files
  - End connection

- Satellite modem can send calls but could not receive them (problem?)
- Transmission success rate
    - 37% total failure
    - 39% partial failure
    - 24% completed
    - Good weeks and bad weeks
    - How do we fix the data dropout rate
- Several attendees commented that significant problems exist with Kermit that probably contributes to poor transmission success rates
- General impressions of Iridium
    - Hardware simple to incorporated and transport
    - Low power consumption is very attractive
    - Provides comms in locations where Inmarsat is too difficult
    - Disappointing success rate of GPS data transfers
    - Why do the data transmissions drop out?

Multi-Link Iridium Satellite Data Communication System; Supplemental Contribution: Overview, Performance and Reliability from Summer 2004 SUMMIT, Greenland Field Experiments July 14-July 25, 2004, Abdul Jabbar Mohammad, Said Zaghloul, Victor Frost, and Dan F. Servey, University of Kansas

- Polar Radar for Ice Sheet Measurement (PRISM)
- Previous work included a 4-channel Iridium system
    - Conclusions from 2003 field experiments
        - Developed a reliable multi-channel Iridium
        - Data communication system based on Iridium satellites that provide round the clock, pole to pole coverage
        - Developed console based link management software that ensures fully autonomous and reliable operations
        - End-to-end network providing Internet access to science expeditions in Polar Regions was demonstrated
        - System efficiency greater than 90% achieved
- Several attendees commented that significant problems exist with Kermit that probably contributes to poor transmission success rates
- 8-channel Iridium System
    - Design Elements
        - Integrated 8 modems and components in an 19" rack mount unit
        - Single board EBX format system
        - PC104 type multi-port serial card
        - Integrated LCD screen
        - Developed GUI based management/control software that configures the unit in all the data modes; a) ISU-ISU DAV mode, b) ISU-ISU data mode, c) ISU-PSTN mode
        - XML database registers all call drops and retrials



- Results
    - Average throughput efficiency was observed to be 95% from test cases where no call drops were experienced
    - Average throughput during the FTP upload of large file was 15.38 Kbps
    - Call drops reduced efficiency to ~ 80%
    - 14 July test (12 hours)
        - Call drop pattern during 8 ISU - 8 ISU DAV mode test
        - 89% uptime with full capacity (8 channels); 98% uptime with at least one modem
        - Total number of primary call drops during 12 hours = 4
        - Average time interval between drops is 180 minutes
    - Results of 19 and 22 July tests presented
        - Call drop pattern during 8 ISU-8 ISU DAV mode test
        - 85% uptime with full capacity (8 channels); 96% uptime with at least one modem
        - Total number of primary call drops during 32 hours = 24
        - Average time interval between drops is 72 minutes
    - Mobile testing conducted with success

- Conclusions
    - Integrated 8-channel system works "out of the box"
        - Reliable and fully autonomous operation
        - The throughput and delay performance of the system using the ISU-ISU DAV mode is better than other data modes

- Newly develop GUI based control software reduced field setup time, increased the ease of operation and is suitable for use by non-technical users
    - System performance based on field experiments
        - Average throughput with 8 channels is 18.6 Kbps, efficiency >90%
        - Average uptime with full capacity using DAV was 85%
    - Average time interval between call drops is 60 minutes and varies a lot
    - Better performance using ISU-ISU DAV modem than other modes
    - System worked well on the move with GPS
- Lessons learned
    - Modem firmware failures were experienced - modem locks up randomly and needs power cycling. Problem is not severe and occurred less than 5 times during the experiment.
    - Due to a bug in Linux pppd software, a call drop on the primary modem still causes the entire bundle to drop
- Recommended future work is outlined to understand and enhance the MLPPP Iridium System
    - Call drops need to be categorized and studied
        - Due to poor signal strength
        - Handovers
        - Other reasons
    - Upgrade modem firmware
    - Develop user-friendly GUI based server software
    - Research and correct pppd bug

Polar Experience with Iridium: Dial-up and SBD, David Meldrum and Duncan Mercer, Scottish Association of Marine Sciences (SAMS)

- SAMs active use of Argos (1980) and Orbcomm (1999)
- Iridium for polar applications
- History repeats itself (Iridium)
    - Early problems with Argos
        - Does it work?
        - Whom do you contact?
            - DBCP (1985)
            - Technical coordinator (1987)
                - Based at Argos Toulouse
            - Successful
- CASES Deployment
    - Three "pancake ice" buoys deployed (between 70 and 72 degrees North and 120 degrees West)
    - SBD packets of 892 bytes - 8 messages per day
    - 2000 messages in total
    - Transmission rate of up to 740 Baud
    - 10% lost messages
    - 100% of messages correctly acknowledged
    - Problems with mail server: data lost!

        - The question was asked if SBD can be sent to more than one site. SBD can now be sent to a maximum of 5 sites.
- GreenIce Dial Up
    - COMMS cost $115K for 6 months
    - Dial up problems with "no connect"
    - Transfer files of 37 Kbytes
    - First 2 weeks the average transfer time was 120 seconds
        - 3100 Baud!
- Iridium conclusions
    - Excellent potential for higher data rates
    - Real-time interaction with mobile
    - 1 or 2 orders of magnitude more energy efficient than Argos or Orbcomm
    - 10 cents/Kbytes for dial-up
    - SBD costs
        - $1/kbyte
        - Easier to implement
        - Expensive for large datasets
    - Still lots to learn
        - **Much better technical information/support needed!**

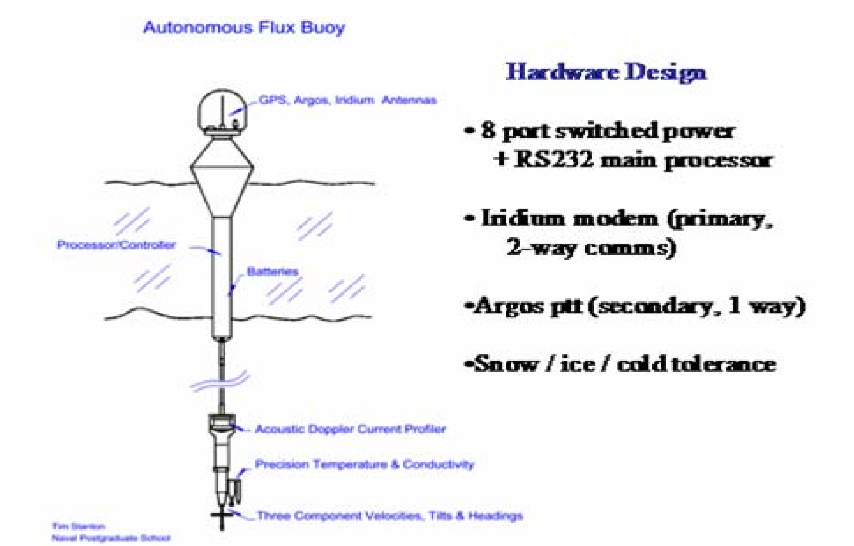
Experiences with Real-time Data Retrieval from Remote Observatories using Iridium Communications Links, Dan Detrick, T.J. Rosenburg, J.E. Etter, and L.F. Lutz, University of Maryland, Rick Sterling, Stephen Mende, University of California, Berkeley and Noel Petit, Augsburg College

- **P**olar **E**xperiment **N**etwork for **G**eophysical **U**pper-Atmosphere **In**vestigations (PENGUIn)
    - System originally deployed with the AGOs - recorded data to on-site hardware which was retrieved during annual servicing visits
    - New data system using Iridium installed in December 2002; linked to CONUS computer allowing real-time data retrieval and distribution
        - Capable of autonomous action to remedy anticipated faults at data acquisition unit or Iridium modem
    - Data made available to researchers in real time via FTP server
    - 2-MB dula-port memory buffer inserted between the data acquisition unit and the Iridium modem with data throughput managed by microcontroller
    - CONUS PC and data acquisition unit programmed to recognize anticipated communication interruptions and perform corrective action
    - 20-MB/day throughput
    - Iridium data system integrated and tested for instrumentation on three AGO systems
    - December to March 2002, 1.5 GB of data was sent from the three AGOs with sustained data throughput of about 20 MB per day
        - Although frequent losses of signal between paired Iridium modems, connections are capable of transferring 98% of the data

        - Data availability achieved by cycling the data acquisition from the VLF Snapshot channel and by commanding the unit to run the channel on/off
- Summary of Iridium Experiences
    - Very happy with Iridium
    - Iridium link
        - AT modem command language (modem-to-modem connection)
        - Layer 2 networking protocol (data line: CONUS DAS<->DAW firmware)
        - Fixed-length data frame (2053 bytes)
        - Verified frame reception
        - No data loss due to transmission errors
    - Iridium disconnections
        - LOS ~4-5/hour, 2002/2003; ~15-20day, 2003/2004
        - Autonomous re-dial
    - Data throughput
        - 20-MB/day (per Iridium channel)
        - Achieved 98% of channel capacity, even with interruptions

Iridium Data Transfer from North Pole Deployed Ocean Flux Buoys, Tim Stanton, Oceanographic Department, U.S. Naval Postgraduate School

- Autonomous Flux Buoy
    - 2-way communications
    - 20 to 200 Kbytes/day data transmission (buoy status, position, ice velocity, mean fluxes) and selected raw data blocks of (u, v, w, T, S)
    - Adaptable sampling
    - 9500 Iridium modem; fallback to summary messages via Argos



- Remote selection of data types to output, sample intervals, sample duration, sub-intervals, remote programming of sample-doubling threshold, remote monitoring of buoy performance parameters and settings and monitor values updated with each transmission
- Data communication solution
  - Iridium direct dial-in to NPS workstation
    - Quick connect, low overhead protocol
    - Relatively simple software design
    - Built in tolerance to "no connects, dropped connects"
    - Built in hand-shaking block by block data transfer protocol
    - Large buffer for outbound blocks to overcome service drops
  - Fallback on one way, summary data transfer via Argos
  - Iridium data transfer performance
    - Statistics for a 6 month period
    - Dial-in success rate of 94.9%
    - 350 connect attempts
      - 325 full data transfer success
      - 12 had no successful data transmission
      - 13 transmitted at least 1 data block
    - 93% of calls were fully successful, 7% had dropped calls
    - Effective throughput of 25 KB transfers was 1979 Baud
    - Effective Baud rate on 132 KB transfers was 2949 Baud
- Summary
  - Iridium is an excellent solution for the 20-200KB/day data transfer requirement in polar regions
  - Two-way data communications is great
  - The direct dial-in protocol was quick to develop and effective, but does not scale well to large deployments
  - Two-way communication exploited to provide adaptive sampling and diagnostic capabilities
  - Care needed with snow/ice covering antenna
  - Would be great if there were a slow-charge method for the super capacitor in the 9500 …this is an unnecessary burden on batteries/switchers at turn-on

Communications in Rapid Environmental Assessment, Alex Trangeled, Daniel C. Conley, NATO Undersea Research Centre, La Spezia, Italy

- Rapid Environmental Assessment definition: "The acquisition, compilation and release of tactically relevant environmental information in a tactically relevant time frame"
  - Wave height, surf zone width, longshore current strength are of critical importance in planning for amphibious operations, mine clearance and special operations
  - Goals include
    - Develop efficient information distribution architecture and communications paths

- EMACS highlights
  - Configurable for a variety of sensors
  - Remote configuration and control
  - Transmission via LEO satellite and/or wireless network
  - Low-cost COTS = disposable
  - Prototypes built for real time surf monitoring
  - Hardware - Eurotech; CPU-1232; Coastal Environmental Weatherpak; Iridium modem
- VSAT, Globalstar and Iridium used for various applications
  - VSAT provides the greatest throughput, followed by Globalstar
  - Iridium deemed "best choice for sensor/portable Tactical Decision Aids"
    - Notes worldwide coverage, end-to-end encryption and dedicated defense gateway
    - Used 9500 modem

National Data Buoy Center's Experiences with Real-Time Data Retrieval from Remote Stations using Iridium; and Data Distribution: GTS and IOOS, Steve Collins, U.S. National Data Buoy Center

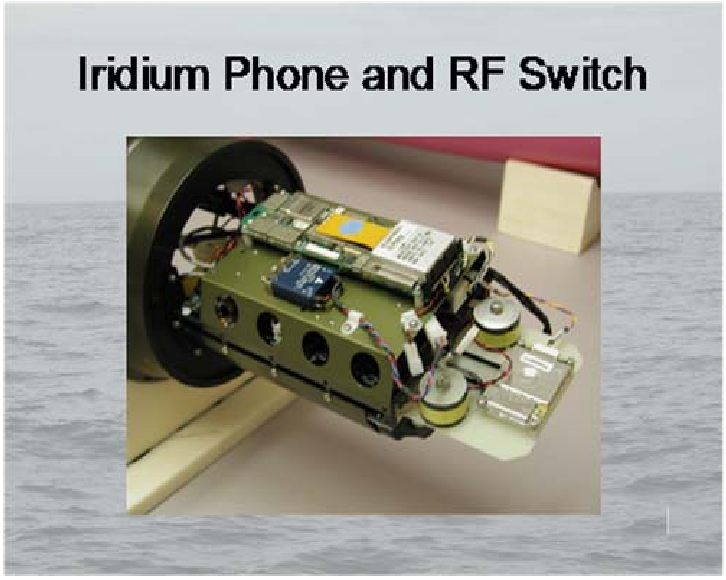
- New requirements are making data streams longer and more frequent
- Data flow for moored buoy system utilizing Argo to include data acquisition and transmission times
- GOES alternative development
  - May 2002 - tasking for non-GOES communication system
    - Iridium selected for best coverage
  - Testing on 3 meter discus buoy conducted in Gulf of Mexico
      - 98% throughput with Iridium compared to 81% for GOES
    - Certified for operational use in December 2003
  - Concept of Operations
    - One "passive" remote modem per station
    - One to several "active" base station modems
    - All calls originated by base stations
    - PC software-controlled base station
      - Remote stations "listen" for incoming calls on programmed schedule for power management
    - Iridium provided real-time data communications
  - Base Station Issues
    - Antenna cable length limited to less than 3bD loss
    - Satellite visibility
    - Will require additional base stations
    - Security
      - No "firewall" on remote station
      - Security limited to general public not knowing station phone number for incoming calls
      - Can not make outgoing calls (Note: Iridium does provide the capability for two-way data communication)

- Anticipated Improvement
  - Multi-channel Iridium modems for base station
    - Reduce equipment cost
      - Fewer PCs and modems
      - Will require software change
- Benefits - Iridium vs GOES
  - Increase in data availability over GOES
  - Lower power requirement
    - Power available for more frequent observations
    - Potential reduction in power system failures
  - Potential for more data
  - Remote two-way communications
  - Potential cost savings in field service using remote "repair" and diagnostics
  - Shore-side event driven reporting possible
- Concerns
  - Telecommunications costs (compared to no usage costs for GOES)
  - Unknown future pricing
  - Base station requirements for comms with 150 remote stations
  - Performance in severe environments/weather events
- Plans
  - Install on 2 new buoys (summer of 2004)
    - Funded by USCG
    - Top of hour GOES transmissions, bottom of hour Iridium transmissions
  - Install on DART buoys
  - Install on prototype USCG Automated Identification System (AIS) equipped buoy

- Potential to install on all moored buoys and most C-MAN platforms for USCG AIS communications
- Overview provided for NDBC data assembly center

Seaglider Communications Performance: Results from Two Years of Open Ocean Operations, Neil Bogue and James Bennett, University of Washington

- Provided overview of Seaglider
  - Used components of Iridium 9500 phone for communications
  - Would have preferred a data modem



- Combined GPS-Iridium antenna developed
  - Pressure-tested to 1000m
  - Available for `$2,200 (randyf@u.washington.edu)
- Software goals
  - Maximize ability to locate and control vehicle
  - Minimize time on surface and energy spent transmitting data
  - Permit graceful recovery from missed or incomplete calls
- Modified xmodem protocol
  - Sent files in fragments
  - Automatic change in buffer sizes during marginal connections
  - Ability to resend whole dives or fragments
- Next steps
  - Compression using gzip
  - Investigate PPP
    - Unsuccessful to date
    - Balky embedded TCP/IP stack
    - Large code size and protocol overhead

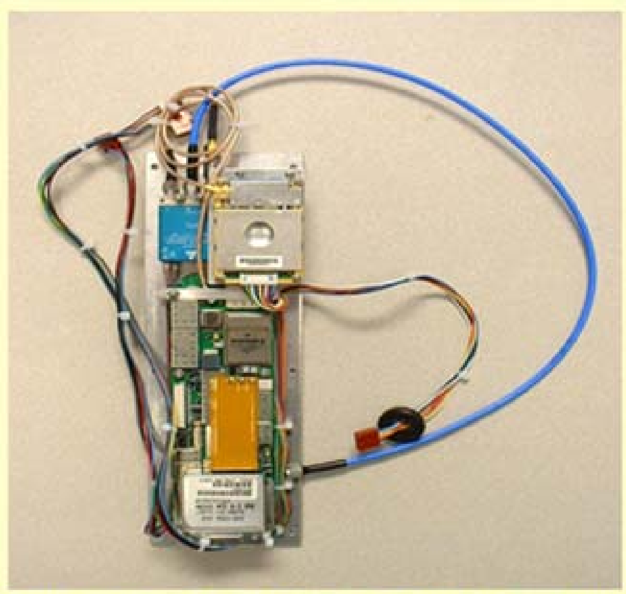
- Testing conducted in the Washington Coast, Gulf of Alaska, and Labrador Sea
  - 1907 dives
  - Connection statistics range form 75% on first attempt in Washington Coast to 35% for the Labrador Sea (SG008)
    - Labrador Sea (SG004) first attempt success rate was 56%
    - Connection statistics deemed to be marginal

ARGO, Profiling Floats, and Iridium, Stephen C. Riser and Dana Swift, University of Washington

- Profiling floats…a modern method of observing the state variables of ocean circulation

- o Great interest in expanding the capabilities to include new sensors and communications links
    - ▪ Issues: power, weight, unattended
- o Communications: Service Argos (~0.1 baud)
- o ARGO is an international program designed to deploy 3000 profiling floats at 300 km resolution - first real-time situ ocean observing system
    - ▪ Present status: 1244 deployed by 14 nations
- o UW float group built and deployed over 400 profiling floats in past 6 years
- o Example float
    - ▪ Profile contains 500 bytes of data (3 variables x 2 bytes x 71 sample depths + engineering data)
    - ▪ Requires 6-10 hours per profile transmitting using Service Argo system
- o Built several floats that use Iridium; deployed as surface drifters in the Antarctic Circumpolar Current
    - ▪ Results show that data can be transferred using real 2-way communication at nearly 2400 bps
    - ▪ Mission parameters can be changed in real-time
    - ▪ Cost is comparable to…Service Argos
    - ▪ Argos: 500 byte transfer require ~9 hr; Iridium: 20Kb transfer requires < 10 min!

Drifter with Iridium unit installed.



Iridium modem (in this case a 9500 phone unit) and GPS unit.

- Used 9500 phone and GPS unit
- Usually a connection is established on the first attempt; in a few cases 2 or 3 attempts are necessary

            - In most cases the full 20Kb file can be transferred in one connection
  - Summary
    - Profiling float technology is advancing rapidly - many uses
    - Major improvement in these floats will come if and when Argos is replaced with Iridium
      - Much faster data transfer rates
      - 2-way communications will be possible
    - First deployment of the ARGO/Iridium float anticipated summer of 2004

First Experiences with an Iridium Telemetry System on the DOLAN Buoy in the Atlantic, Eberhard Kopiske, University of Bremen

- Overview presented on the DOLAN Sensor/Telemetry
- DOLAN Surface Buoy
  - Tracking: Inmarsat Mini-C
  - Orbcomm communications
  - Satel Packet Radio
  - Wind speed/direction
  - Acoustics Sub-Sea Modem
- Iridium Telemetry on DOLAN buoy
  - NAL Iridium modem
  - Embedded PC (ELAN 520 Processor)
  - GPS Sensor
  - Automatic e-mail (GPS data) generated every two hours
- Experiences with Iridium
  - Satellites accessible from every location on the Atlantic
  - Iridium sessions last for 2 to 60 minutes without break down
  - Log-on to satellite is difficult during two time windows - UTC 7:00 and UTC 10:00 for approx one hour each
  - Much better availability of satellites for high latitudes than for example Orbcomm
  - Problems occurred during development and testing
    - The structure on how Iridium works is not very clear
      - Settings like 'AT+CBST=7,0,1' and prefix number for dialing
      - How can we access the modem (which prefix number) via Iridium?
  - Short Burst Data (SBD) will be very useful but it wasn't available for testing (Note: SBD has been completed and provides a cost effective means to relay packets of data)
- Experience with DoD SIM Cards/NAL Modem
  - Satellite signal strength not available via AT commands (NAL Modem) only one LED indicates a satellite in view (Note: you can now check signal strength using an AT command)

- 9505 mobile phone more robust than NAL 9500 modem
  - Many situations phone can log on the satellite when modem could not
  - Most of the received modems were not able to log on
- Computer does not recognize “No Carrier” from Modem (DSR)

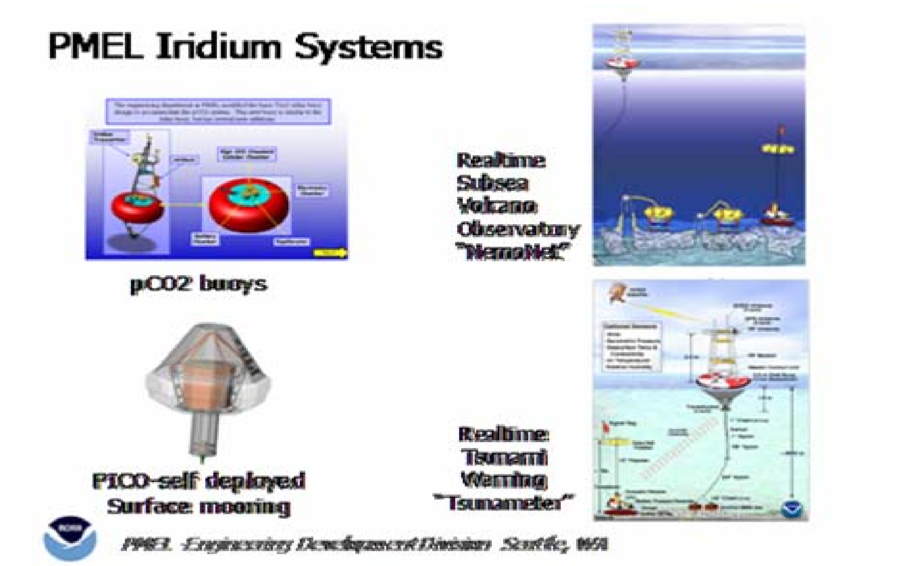
➢ Our “wishes”
- Standby mode with low power consumption (Note: Standby mode now available)
- Support of cellular AT commands
- Higher data rates
- Compression
- Comprehensive documentation of hard- and software interfaces
- Firmware upgrades (Note: Firmware has undergone several upgrades)

An Overview of PMEL Iridium Ocean Observatories, Christian Meining, Pacific Marine Environmental Laboratory

➢ PMEL Engineering Development Division
- Mission is to support PMEL research effort with innovations in the fields of digital and analog electronics, mechanics, materials, and software engineering

➢ FY03 Support
- 30 cruises on 11 different ships; 260 DAS
- Over 180 moorings deployed, 48ea 40’ container shipped
- End-to-end support serving NOAA’s missions

➢ Developed a number of PMEL Iridium Systems

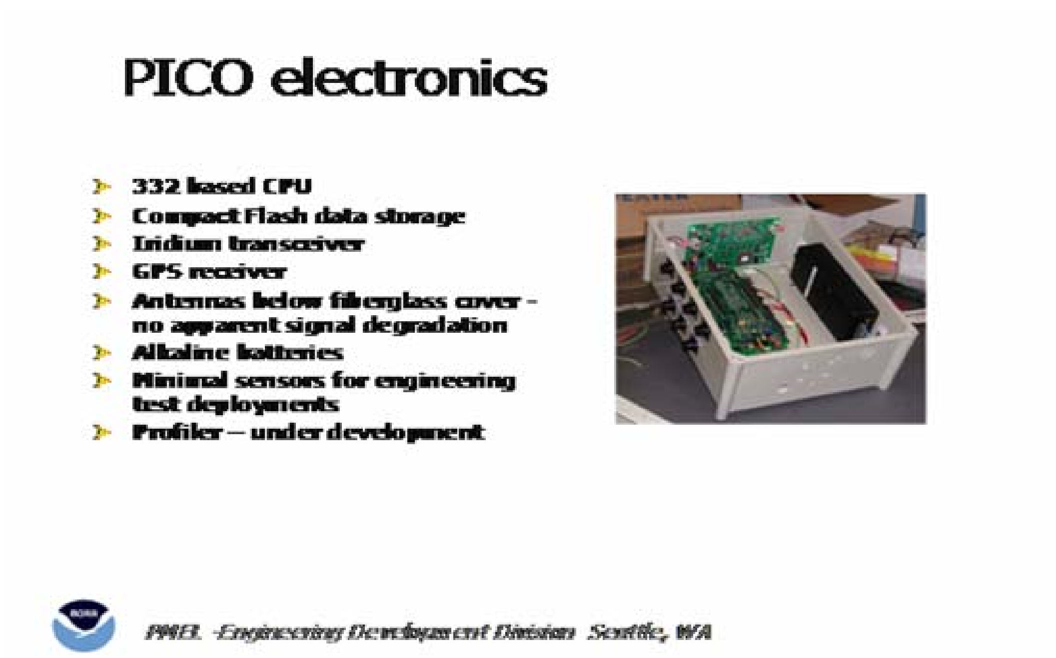


➢ NemoNet Goals - understand and quantify volcano’s impacts on surrounding ocean’s…environment

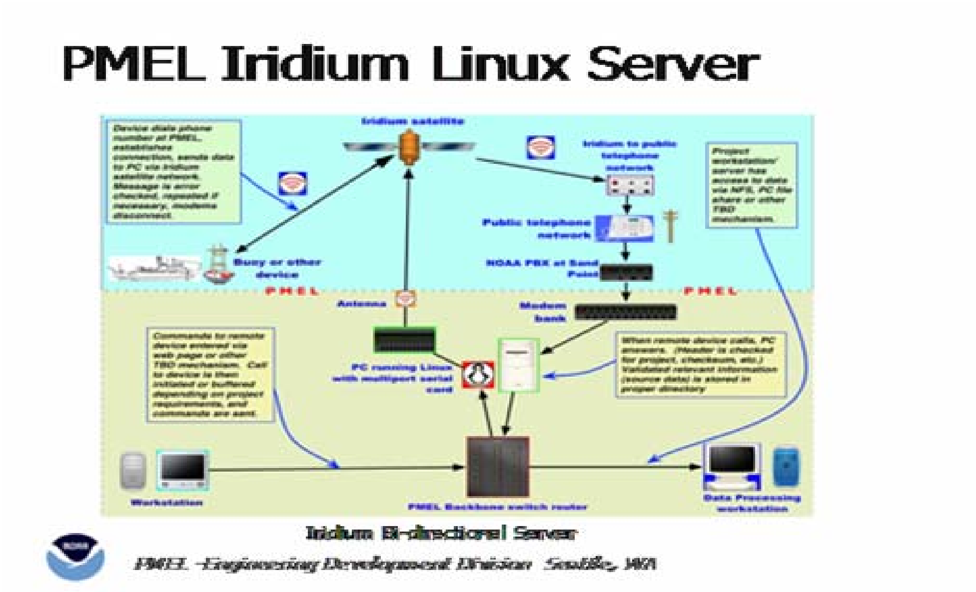
- Real time bi-directional buoy-based ocean observatory (1yr) w/low bandwidth (10Kb/day) needs
- Web based
- Iridium replacing Orbcomm

➢ Prototype next-gen "Tsunameter"
  - GOES (Sutron) `80% return (some firmware issues)
    - High power!
    - Not bi-directional
  - Iridium 95% return
    - Protocol based on acoustic modem experience
    - Will Iridium be around?
    - Iridium can contact buoy to send at higher data rates - very happy with the data rate provided by Iridium
  - Wants desktop to seafloor in 3 minutes

➢ PICO (Platform and Instrumentation for Continuous ocean Observations)
  - "Buoy in a box" - internal antenna
    - Costs are high
    - Complex and dangerous operations
    - Large buoys
    - Limited subset capabilities
    - Vandalism problems
    - Design challenges outlined



➢ Asset Tracker: Iridium Position System developed along with the PMEL Iridium LinuX Server



- Future development: Air Deployable Surface Buoys?
  - Viable alternative compared to UNOLS and NOAA ship costs
  - Worldwide deployment capability
- Future Iridium Development Wish List
  - Data Services Provider
    - Add metadata, calibrations GTS, bi-directional, etc.
  - Higher QC on Iridium modems
  - TCP/IP for embedded systems
  - Reduce dependence on POTS (plain old telephone system)
  - Smaller, cheaper, faster
- Much confusion on architecture - SMS, SBD, dial-up, RUDICS, direct internet
- Need funding for dedicated technical support

Real-time Over-the-horizon Communications for MBARI's Ocean Observing System AOSN II - AOSN II Video, Lance McBride, Monterey Bay Aquarium Research Institute

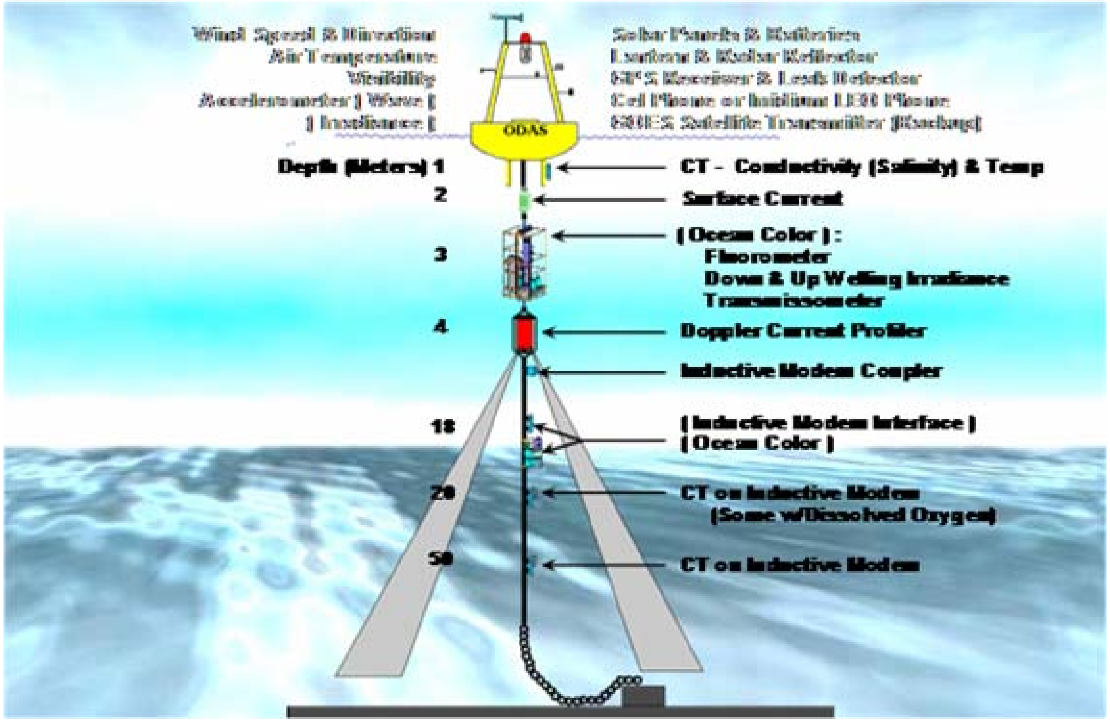
- MBARI Ocean Observing System (MOOS)
  - Buoy
  - AUV Dock
  - Benthic Instrument Node (BIN)
  - Stand-alone remotely deployable cabled observatory
  - Delivers OEM cable to seafloor
  - System requirements
    - Readily configurable
    - Real-time interaction
    - Event response
    - Affordable
  - MSE 2005 Benthic Science Instruments
  - Data Requirements - as planned
  - 257Kb/day to 3.3MB/day

- Telemetry - Data Publishing
  - Buoy dials shore modem periodically
  - Establishes PPP link to portal computer
    - Buoy publishes recently archived data on portal
  - Buoy disconnects
  - Portal publishes data to shore-side data system through firewall
- Telemetry - Instrument Services
  - Buoy dials shore modem periodically - or RF reset initiated
  - Establishes PPP link to portal computer
    - Portal publishes buoy DNS information
  - Shore computer opens remote console on buoy via ssh
  - Shore computer establishes console to instrument
    - Remote configuration/diagnostics/driver updates
    - Add instrument and remotely start instrument service
- Iridium and Globalstar considered
  - Iridium covered all areas of interest - Globalstar did not
- Globalstar @ 7.4kbps; Iridium @2.4kbps
  - More Iridium airtime needed to send data - higher airtime cost
  - Globalstar testing and integration
    - Qualcomm GSP-1620 utilized
    - Reliable 7.6kbps for IP traffic over PPP line
- Iridium testing
  - 9500 Iridium modem
  - Fixed mast antenna model SAF5350
  - Buoy spends most time between 0 and 20 degrees
  - Signal strength noted as issue
  - Results
    - FTP'd multiple small files of varying formats
      - .zip, .jpg, .gif, .pdf, .txt, .rtf
      - File sized from 1.5 to 15kB
    - Tilted antennas to predefined heading and angle to simulate buoy motion
      - Dial-up only
    - Also transferred large text file (100kB to 1MB)
  - Iridium testing results (small files)
    - "Dial-up data service" (tested in Linux) - AVE 2.04 kbps; MAX 6.0kbps; MIN 1.28kbps
    - "Direct Internet" service (tested in Windows)
      - Compression from Brand Communications
      - AVE 6.76 kbps; MAX 26.24kbps; MIN 1.36kbps
    - Noticed lower bandwidth at low angles than high angles
      - Suspected antenna gain pattern
  - Iridium testing results (large files)
    - "Dial-up"
      - MAX: 2.6kbps
      - AVE 2.5kbps

            - MIN 2.2kbps
        - “Direct Internet”
            - MAX: 15.0kbps
            - AVE 13.9kbps
            - MIN 13.1kbps
        - Dropped link 4 times out of 16 at around 600kB
    - Iridium testing (compression)
        - Large files compressed with WinZip
            - 100kB to 1.24kB; 500kB to 3.39kB; 1.02MB to 6.055kB
    - Changed components based on previous testing
    - Used 9505 Iridium phone with data kit and auto adapter
    - Test conclusions
        - Use optimized antenna for application
        - Transfer small files
        - Transfer pre-compressed files
- Data requirements
    - CIMT in Monterey Bay: 4.1MB/day
    - MTM2 in Monterey Bay: 1.1MB/day
    - Airtime cost; Iridium higher than Globalstar
- Future Plans
    - Reduce link overhead
    - Implement shore initiated link establishment
    - Deploy Iridium on buoy in regions outside Globalstar service area

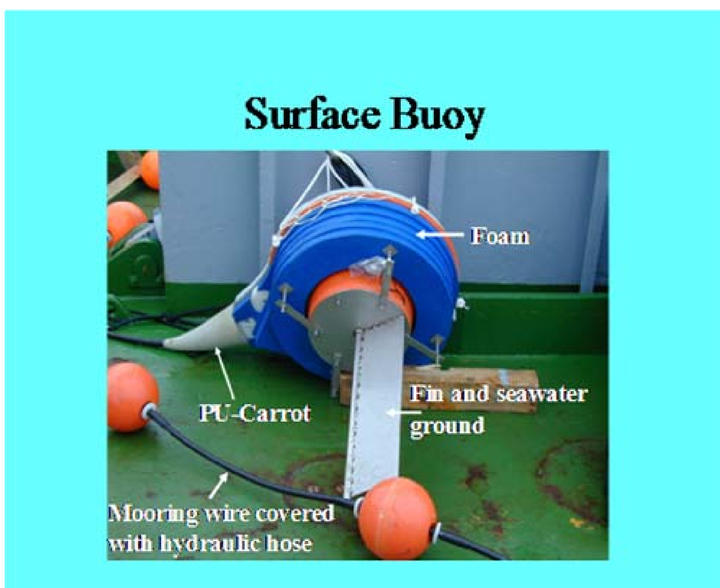
Gulf of Maine Ocean Observing System (GoMOOS), Robert Stessel, University of Maine

- Moored buoy system utilizing cell phone or Iridium LEO phone
- GOES satellite transmitter (backup) Design goals
    - Real time data acquisition and display
    - Reliability
    - Serviceability
    - Expandability
    - Low Power Consumption
- Future Plans
    - Fixes
        - Cell phone - cold WX
        - Met sensor - icing
        - Cable breakage
        - Instrument batteries
        - Solar Panel blowouts
        - Verify Power Budget
    - Additions include wave-3D, humidity, and active radar reflector



Experiences with a Small Moored Surface Telemetry Buoy Including the Subsurface Inductive Data Link, Andreas Pinck, Institute für Meereskunde, Universität Kiel

- Provided overview of buoy system with subsurface data link



- System specifications
  - Data sampling rate: 2h
  - Transmit rate: 4h

        - Repitation rate: 20s
        - Transmit duration: 110min
    - Data transmit mode: cycle of 4 blocks at 32 bytes
    - Information/time: 768byte/day
    - Power consumption/msg: 0.25Ah/kBytp
- Utilized ARGOS transmitter
- Next step is to utilize Iridium

Use of Iridium in a Small Moored Buoy, and on a Large Commercial Vessel, Jonathan Campbell, Southampton Oceanography Center (SOC)

- Iridium applications at SOC
- Telemetry buoys on Inductive Moorings for the RAPID Climate Change Programme
    - 8 inductively coupled SeaBird CTD
    - 7 inductively coupled SonTek ADCP
    - Main underwater buoyancy at 50m
    - Iridium equipped buoy on 250m neutrally buoyant tether
    - 14 months duration
    - Iridium 9522 LBT
    - Seabird Inductive Modem
    - Trimble GPS receiver
    - 8 analogue sensor channels monitoring voltages and temperatures
    - Iridium Scheme
        - All calls initiated by buoy according to preprogrammed schedule
        - 66 byte SBD message sent every 2 hours with position and status parameters
        - Dials up every 8 hours and transfers up to 13kB of data
        - Sends data in 2kB blocks and waits for handshake response
    - Results
        - Buoy deployed 28 Feb
        - Inductive link damaged during deployment
        - Iridium communications ceased on 30 March
        - Unable to locate buoy on 8 May
        - Mooring will be recovered in Spring 2005
    - Iridium performance of the 31 days
        - All 377 SBD messages received
        - All 93 dial-up messages received
            - 5 of these required a second attempt
        - Due to broken inductive link, all dial-up messages were only 3kB
- Testing of Combined Iridium/GPS antenna for use on Floats
    - Deployed 29 April
    - Trident systems developed antenna
- European Ferry Box Project
    - Cost effective platform for measuring short and long term changes in Bay of Biscay
    - Uses Orbcomm since 2002

    - Sends 160byte message every 10 minutes
    - Data displayed on website within 1 hour http://www.soc.soton.ac.uk/ops/
  - Iridium to be installed next month
    - Running parallel with Orbcomm
    - Dial-up every 4 hours
    - Use simple 2kB block transfer protocol

Telemetry for a Coastal Ocean Observing System, Preliminary Results using the Iridium System, Chris Calloway, University of North Carolina

- Iridium used in multiple applications

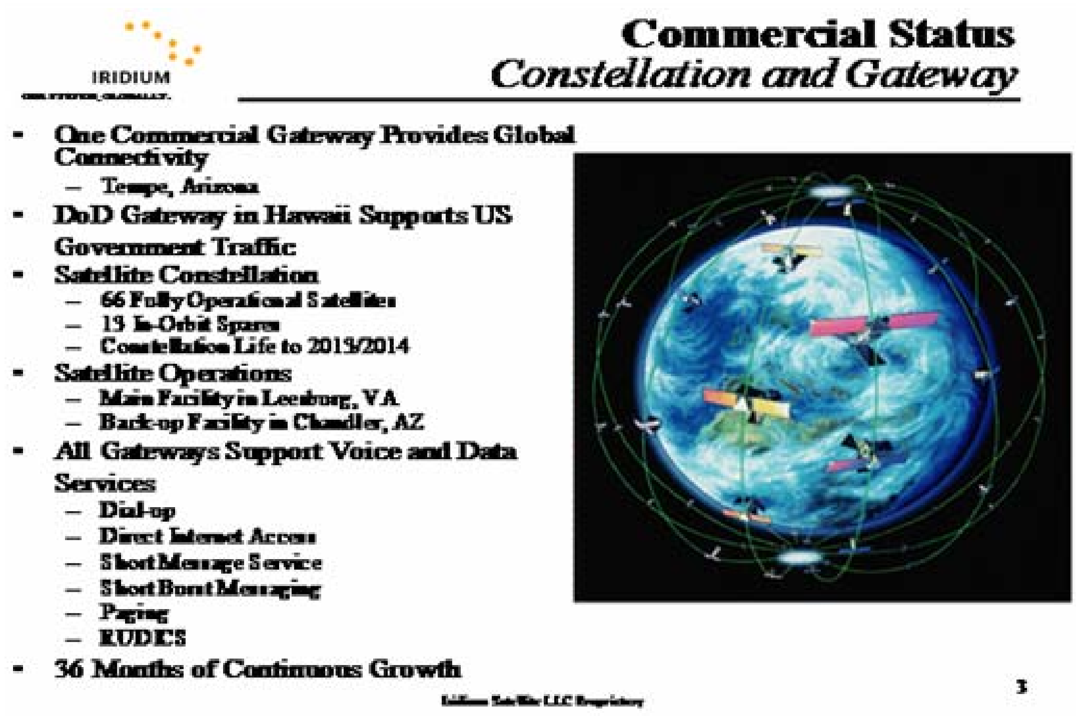
    - Five Iridium efforts:
      - UNC: NCCOOS towers and Slocum Glider
      - USC: Caro-COOPS buoys
      - GA Tech: TriAXYS buoys
      - U of Miami: SWAMP profiler
  - Caro-COOPS buoys
    - ISU to ISU
    - Dedicated data logger (ZModem)
    - Shore dials in to observing platform
    - Low throughput (100 bytes/sec)
  - NCCOOS towers
    - ISU to ISP
    - SBC with instrumentation buss
    - ISU "calls home"
    - High throughput
    - 2MB/day

- Utilized Iridium 9500 data modem
  - Median burst rate: 7503 bytes/sec
  - Average power consumption: 1 watt
  - Transfer Rate Statistics (bytes per second)
    - Points: 460
    - Average: 6563
    - Median: 7503
    - 25 Percentile: 4417
    - 75 Percentile: 8334
    - Std Dev: 3047
    - Minimum - 200; Maximum - 13582

- To do (includes)
  - GPL; more statistics (connect rate, connect time); test 9505 modem; Iridium Data Gateway; ISAPI; Linus

Iridium Satellite LLC, System Update, Scott Scheimreif and Kent Keeter, Iridium Satellite LLC

- Corporate overview provided
  - System acquired Dec 2000
  - Commercial service re-introduced in March 2001
  - Vertical market distribution strategy for voice and data services
  - Strategic relationship with Boeing for satellite operations and maintenance
  - 2013/2014 constellation life
- Uniquely satisfies DoD's EMSS requirements
  - Global pole to pole coverage
    - Polar regions
    - Ocean areas (no gaps)
  - Uses Cross-Linking Satellites to relay data to secure DoD owned and operated gateway
  - Independent from foreign infrastructure
  - Seamless DSN Connectivity
  - Enhanced DoD Services
  - Secure on-the-move global voice/data for DoD's special requirements



- Iridium Operational Usage includes
  - Command and control
  - Targeting
  - Tracking
  - Voice and data
- Provided overview of Iridium communication capabilities
  - Dial-Up
    - PSTN or ISU
  - Direct Internet/RUDICS (**R**outer based **U**nstructured **D**igital **I**nter-**W**orking **C**onnectivity **S**olution)
    - Faster connection time
      - 15 seconds compared to 40 seconds for dial-up PPP
    - Transparent compression seamless connect/disconnect
      - Reduces on-air charges
      - Maximizes ISU battery life
      - No tail-end charges at Gateway
    - Smart connect
  - Short Burst Data (SBD)
    - "Ultra-efficient" way to transmit small accounts of data
      - 70 bytes in ~1 second
      - High reliability
      - Two-way exchanges
      - Limited power source
- Data After Voice (DAV) has shown a 7,400% increase from September 2001 to January 2004
- Attendees asked where they should go to procure SIM cards

- Value Added Resellers offer airtime
- It was noted during discussions that RUDICS is standard or PPP, but PPP was is not available at the DoD gateway (PPP is now available at the DoD gateway)
  - RUDICS doesn't work with Linux
- A discussion item during the brief was that a DAV code problem had been causing units to "power-down", but that a fix has been implemented
- It was also noted that a PSTN can call an ISU that has a DoD SIM card but that a specific card is required

The second day of the Workshop began with an update from Dr Ngoc Hoang, President and founder of NAL Research Corporation. Dr Hoang noted that Iridium hardware had been significantly improved since the initial 9500 modem was developed. Many of the problems addressed during the Workshop had been corrected in the 9505 modem. Of particular interest were two issues. The Data-After-Voice (DAV) capability reduced latency but contained a bug in the firmware. The problem was isolated and corrected. Workshop attendees who have the 9500 modem can return the units to have them re-flashed with updated firmware. The second issue involved signal strength fluctuation that could cause the modem to lock up if operating in a continuous mode. This problem was corrected in the 9505 modem. He noted that the design of the next generation hardware, referred to as the Daytona, is underway and that a few prototypes will be available in the September timeframe. The Daytona should be ready for full scale production in about a year and will replace the DSC bus with a DPL bus. The new phone will be referred to as the Monaco.

Dr Hoang addressed an ONR effort to develop a "soft SIM" capability that will utilize software contained in the micro-controller, eliminating the need for an actual SIM card. It would then be possible for multiple Iridium units to share a single SIM designator. Units could be programmed to report at varied intervals to ensure they do not interfere with each other. However, the effort is being delayed pending development of the Daytona model, which will have difference interfaces and protocols. Iridium Satellite LLC expressed concern as to how this capability would be managed and controlled.

In response to questions from the audience, Dr Hoang explained how the 9505 phone is different from the modem. While there are only minor differences in the RF boards, the units utilize different sets of firmware and go through different boot-up processes. There is no difference between the 9505 and 9522 modems from a RF standpoint; both use the same OEM board. However, NAL adds other circuitry and firmware. In addition, NAL Research offers the only Iridium modems that have been HERO (Hazardous Electromagnetic Radiation to Ordnance) and HERF (Hazardous Electromagnetic Radiation to Fuel) certified by the Department of Defense for use around munitions and fuel.

Several issues were raised and discussed:

- Chris Calloway, University of North Carolina, stated there is concern regarding the ownership of data - the architecture should take this into account
- Several attendees addressed the need for a driver specifically in support of ocean platforms
  - If was asked if the source code could be made available for attendees to develop drivers; source code is proprietary and can not be released
- Documentation for the 9505 is good, but documentation for the 9500 modem is lacking (Note: Documentation can be located on the NAL Research web site; http://www.nalresearch.com)
- Training was addressed in depth
  - How to?
  - What works? What doesn't work?
  - Who do we contact?
- List hardware and firmware versions, related bugs and corrections/work arounds
  - Direct internet using Apollo emulator won't work with Linux
  - Can use Linux effectively - PPP to internet
- Inmarsat signal will drown out Iridium
- The Direct Internet with the Apollo emulator will send data from where the connection dropped and not send the whole data file again (spoofing)

Dr Piotrowicz provided guidance on the Breakout Groups. Areas to be covered include:

- What are the critical issues that need to be addressed?

  - Hardware
  - Software
  - Protocols
- What should the support system/network look like?
  - Level of live support
  - Self-help tools
  - Who should provide support
  - Who should fund it
- How can we control quality and distribution?
  - Standard data and products
  - Real-time vs data base
  - Free access or subscription
  - Who provides the service
  - Who should fund the service

In response to a question, Dr Piotrowicz stated that Omnet would not play a management role and that a problem in their business plan prevented them from provided services to the oceanographic group. However, a John Hopkins wireless project could possibly provide the framework for such support.

Attendees were separated into three Working Groups

- The Mobile Applications Working Group - Chaired by David Meldrum
- The High Latitude Applications Working Groups - Chaired by Dan Detrick
- The Fixed Platform Working Group - Chaired by Christian Meinig

The final day of the meeting began with a live demonstration of the Emergence Transmission Aerospace Network (E-STRAN) by the King County Sheriffs Office. This demonstration utilized Iridium (ISU to ISU) for data communication and to provide a "chat" capability between an officer in his vehicle and the control station.

Following the demonstration, Working Group debriefs and discussions were conducted.

The Mobile Applications Working Group outlined the following issues

- Hardware/software
  - Remote wakeup capability is needed - incorporate pager feature?
  - More detailed documentation is needed
  - Backwards compatibility - guaranteed!!
- Support
  - Repository of information needed
    - Exchange of info on what does/doesn't work
    - Access, maintenance, structure hosting - needs to be accomplished
    - Who maintains the site?
  - Too many tiers/tears
    - VAMs/SPs are not impartial
  - Iridium education opportunities
    - Community rep/general users
    - Iridium volunteered - who will fund?

- Circumvent NDAs?
- Funding
  - Argos/DBCP model? Coordinator in Argos building but funded and reports to users
  - Non-profit entity to support research/operational (non-profit) users
  - Non-profit SP
- Improved data dissemination/QC needed
- Different models for different data types

Steve Piotrowicz stated that the standardization of modem protocols would be advantageous. Pooling information and running a series of test with various protocols would be a move in the right direction.

The High Latitude Applications Working Groups addressed the following issue

Technical Issues

- Hardware
  - Antennas
    - Placement application notes are needed
      - Manufacturer's/user's recommendations
    - Operational data regarding sky/satellite visibility issues
      - Minimum field-of-view angle for optimal sky coverage? Dr. Hoang suggested minimum elevation angle of 10-degrees (above the horizon) along the satellite path, but an obstruction angle of 45-degrees would likely result in almost-certain LOS (loss of signal)
    - Radiation patterns: manufacturer's information regarding the radiation pattern of an antenna should be provided
      - Assistance should be provided in selecting an antenna for a particular application for optimizing the sky coverage
    - Transparency: antenna manufacturer's/user's recommendations
      - Antenna covering/obstruction material transparency
      - Working group participants suggest that dielectric-type materials (*e.g.,* glass/Plexiglas/fiberglass) have minimal impact on reception, but metal, ice and snow can reduce visibility
      - Under-ice antenna development: information about existing antennas that would enable Iridium reception below sea ice would be useful; otherwise, development of such capability should be explored
    - Coaxial cable losses: What 'work-arounds' are available for the Iridium modem 3dB RF signal loss limit? Suggestions include the use of an active antenna and the use of line drivers to extend RS-232 data cable to ~100m

    - Minimum antenna separation distance of 1 foot should be sufficient, although the 'hockey puck' antenna appears to tolerate closer positioning.
- Satellite coverage
    - There is up to 10-11 satellite footprint coverage at high latitudes, although only one will be 'active'
    - There is a 10s 'handoff' overlap in satellite coverage, to permit temporary LOS, for example when driving under a bridge or tunnel
    - Satellite coverage has been improved over Antarctica through arrangement with Iridium LLC
- Latency: Characteristics of the signal delays inherent in the modem, satellite, and gateway should be made available; these should include minimum, average, and maximum expected values
- Alert system: a mechanism/system should be established that would alert current Iridium users to hardware/firmware/software upgrades, and should include specific information about the procedures to be followed in getting access to them. For example, an RMA could be provided for the return a modem for upgrade.
- Modem
    - Better information should be available to the user regarding RF signal/power level, other than the AT+CSQ 0-5 value now available. For example, the 'link margin' should be available through a specified procedure.
    - A 'self-test' mode should be incorporated into future modems and specific access procedures should be detailed
    - Detailed information about new features, such as the Soft-SIM capability, and SBD operating characteristics should be made available to users
    - Current users should be made aware that most problems are being experienced by users of the 9500 series modems, and these 'disappear' in the 9505 and later models
    - There should be a resource available for information regarding known problems with current hardware, as well as established procedures for mitigating them
    - Information should be made available regarding avenues for getting 'customer support' for modem/Iridium problems; since most users in the Ocean/NSF group are application developers ('experts') established self-help procedures would allow them to solve most problems on their own. No avenue currently exists for getting hardware support from Iridium LLC.
- Iridium service improvements
    - The link margin in SBD mode is 22 dB, but only 12.5 dB in 'dialup' mode
    - In order to improve Iridium access to a specific unit, for example for SAR missions or other safety-related purposes, the priority

rating for a specific unit could be increased; however, it would be extremely difficult to increase the link margin for a specific unit
        - With SBD, a valuable capability would be to request the Iridium registration information, by email, to include the date/time and location. This would allow tracking of the unit, without the need for sophisticated protocols.

- Software
    - Modem
        - Specific initialization procedures should be made available. Procedures should be made available for modem conditioning, such as 'burn-in' periods. (Dr. Hoang related that NAL Research performs a 30-minute burn-in for all modems).
        - Operational procedures should be specified/published for making Iridium connections in modem-modem, modem-landline, and modem-internet usage, and should include examples/details about what not to do.
        - Existing 'success stories' should be available to current and new users, and should include software code and documentation
        - All application/testing software should be made available for the Linux operating system, as well as Windows
        - Software application notes should be made available, describing procedures that are known to work, as well as those that don't
- Protocols
    - Information should be made available that describes which standard protocols work, to include specific details about operating procedures/ characteristics
    - Specific information about needed 'tweaking' should also be available. For example mitigating delay/latency effects inherent in the Iridium system, as well as information about configuring the protocols for operation under various platforms (Windows/Linux)

- What should a support system/network look like?
    - Level of Live Support
        - Hardware/Service Providers have established support procedures
        - A support Point of Contact would be valuable for the Iridium user community, perhaps similar to the Service ARGOS system
        - Instead of 24/7 on-demand availability, a 24-hour response time would be acceptable
        - Web-based user support links would be valuable, but a better avenue should be available for day-to-day problem resolution
        - <u>Action item: Contact Pat Smith to request icecomms participation by Ocean.US group</u>
    - Self-help Tools
        - NAL Research provides signal strength monitoring procedures at ftp://nal-psi.com, user account 'nal_ftp', password 'password'

        - A list of available tools/links should be published, containing for example existing user software application code and procedures
        - A web site would be ideal for information and self-help procedures
        - A procedure should be established/published for assisting users to get support
        - A standardized ‘form’ or procedure should be provided that would help the user ‘ask the right question’; for example, this could prevent ‘It doesn’t work’ types of support requests.
    - Who Should Provide Support?
    - Who Should Fund Support?

- How can we QC and distribute standard data products? This activity was deemed to be application-specific, and no general recommendations are offered.
    - Real-time vs. database?
    - Free access or subscription?
    - Who should provide service?
    - Who should fund service?

The Fixed Platform Working Group address the following issues

- Solutions will be general to all satellite systems
- Fixed platforms: buoys/towers
- Technical Issues
    - Hardware
        - Interface specifications
        - Live documents
        - Power consumption
        - Super cap
        - 2000uF cap in parallel
        - UART hang-up
        - Auto-shutdown
        - Antenna
            - Leaky
            - Orientation/gain
            - Availability of marine antenna
            - Cable length vs. active antenna
                - 3dB max
                - Connectors
                - cases/enclosures
        - Vibration - screws loosening in 9500 units - 9505 better
    - SIM card holders
        - Foam to retain
    - RF compatibility between separate RF subsystems
        - Check signal with mobile phone (Note: you can now check signal strength on the modems via AT command)

- RF shielding of future unit
- Humidity/temperature operating range spec
  - On NAL website
- Nitrogen purged/vacuum/pressurized case
- Industrial vs. commercial semiconductor temp ranges
- Signal strength
  - At transceiver
    - Signal strength
      - Higher levels
      - Bars vs. dB
  - And at satellite
  - Ability to check while using Windows RAS
    - RAS takes over serial port
- Hardware interface stability
  - Stability of hardware
    - Backward compatibility
      - Serial port will be compatible
    - Connectors
    - Physical size
    - Ruggedized
  - DSC vs. DPL
    - What is it?
- Transceiver Quality Control reports
  - Standard testing methods documented and available
  - Configuration sheet
    - IMEI number readily available
    - Firmware version
    - USB vs. Serial
    - Modem type (GPS vs no GPS, etc.)
- How to get GPS data from dual purpose units without SBD
  - For systems that haven't implemented email data processing
  - Need more details on GPS capabilities
- MXU
  - 4 LBTs
  - Designed to connect to a PBX
  - Splitter 2 LBT channels per antenna
  - Replace Inmarsat on ship
    - Inmarsat RF lobes incompatible with Iridium
      - 100m separation
- Software
  - Soft SIM – details please
  - Future availability
- Firmware
  - Flash
    - How to flash modem
      - Done at NAL

            - Software for configuring GPS on NAL website
    - What's the latest?
    - How to read what we have
    - List of versions with known bugs
- Standardized libraries for embedded platforms
    - Communications
    - Definition of software interface
- Security
    - VPN/Tunneling
    - How to secure phone line
        - Dial-in security
            - Call window
            - Buoy calls home & checks for file
            - OOB signal to dial
- Linux
    - PPP fix
    - PPTP fix
        - Likely solved by inserting a computer to provide a constant data stream
- Modem drivers vs. modem applications
    - Optimized for application
        - Saving time by optimizing baud rate
            - Reduces negotiation time
            - 4800 likely
        - Compatibility
            - V.92 vs. v.24
        - Ability to create one
            - Requires information on hardware
    - Platform dependency
        - Unique operating system & hardware
            - Windows CE
            - StrongARM
            - Persistor
            - Onset 8
            - Embedded Linux
            - Campbell Scientific
- Compression
    - Apollo not really useful, since Windows Notebooks not used on ocean platforms
        - Make direct internet Linux compatible
        - 008816000021 – direct internet number for both gateways
            - Spoofing
            - Smart connect
            - Windows dependent
            - 10k with compression
        - PPP vs. FASTPP

            - PPP 8816000022
                - Generic login
            - FASTPPP 8816000023
                - No login
            - Needs to be RFC compliant
            - Linux compatible with RFC compliant PPP
    - Documentation of levels of compression
        - What level/What's done/Where?
            - Built into modem
            - Built into Iridium
                - Turned off on gateway due to Apollo/Gateway ISDN link
        - RUDICS faster than Apollo due to lack of required decompression on RUDICS
- Protocols
- Technical expertise
    - Recommendations for protocols based on experience
    - Simplest vs. bidirectional vs. data quantity matrix
    - Most efficient & cost effective use decision matrix
    - SBD: data < 2k; not "bidirectional" – 1 ½ directional
        - What about published/sent directly to FTP server
    - RUDICS
        - No limit of phones to 1 IP address
        - 5 port increments (commercial)
            - Simultaneous connections
        - Connections
            - T1/E1
            - Frame Relay
            - Ethernet
            - VPN
            - Serial
            - Fiber, etc.
        - Dial-UP/Direct Internet/DAV
- Voice calls/Talk slower
    - Use Jabra headset
- New Services
    - Data published/sent directly to FTP server
        - Talk to NAL
        - A cross between RUDICS & SBD
        - Removes necessity of TCP stack on remote controller
    - Matrix
        - Services available
            - What it does
            - What is needed to use it
            - Size/Time/Costs
                - Activation

            - Monthly vs. minute vs. data quantity
            - Per unit
        - Who to call for more complex services
            - Stratos or
            - SRA International
                - Paul Torick 703-502-1208
            - Tier 1
                - Offer both hardware and services
                - Requires 24hr tech support
            - Tier 2
                - Iridium lets Tier 1 choose
    - What protocols are available
        - Documentation
- Support
    - What level of support is needed?
    - Email support
        - For development
    - Information pushed out to users
        - Critical (i.e. DOD Sims down from xx:xx to xx:xx)
        - Who originates information
            - Oceans.US?
    - 24/7 live required
        - For operations
        - Different requirements for different application
        - Civil defense/military
        - Search and Rescue
        - Depends on problem
- One-stop for support
    - Central coordinator/Ocean advocate within Iridium
    - What expertise at Iridium tier levels?
- Online access to individual SIM call logs
- User experiences
    - Documented successful results
    - Documented completed systems
    - Problems encountered & solutions
    - Lessons learned & how we'd do it differently
    - 9505
        - Available on NAL FTP site
- Lack of vs. centralization
- User review of documentation
- How to build feedback loop
    - Email list
        - Too many emails
            - Perhaps a user configurable forum/list
                - (i.e. Yahoo forum)

            - Iridium.Pioneers
                - Lack of communications
        - USENET newsgroup
            - Messages don't drop off
                - If our own
            - Community owned
            - Persistent messaging service
                - Forum (i.e. Yahoo forum)
                - Newsgroup
        - WIKI
            - Set of user modifiable web pages
                - Growing community maintained website
        - Moderator
            - Iridium NSF/Oceans.US advocate
        - Serves larger user community
        - Company participation
            - Iridium
            - NAL
            - Etc.
        - Service provider summarizes comments/lessons learned
            - Into FAQs
        - Training
            - Provided by Iridium/NAL
            - How often
            - Once-a-year for oceanographic community?
                - How many people
                - Limit groups 10-15 people
                - Multiple groups
            - Best if just marine oriented
            - Best if co-located with major ocean conference
                - OCEANS or other
        - Who supplies support
            - "Who" vs. "Funding"
            - "Who" = someone from community of users
            - Technically competent
        - "Funding"?
            - Which of many governing bodies to decide?
            - Ocean.US to request
        - Vendors to provide out of the box product support
            - Specific product support
        - Someone to provide info on new Iridium services
            - Systems level documentation
            - Main point of support
                - Refers to vendor if needed
                - Predicted level required high

            - # of instances will grow
        - Getting identified problems out to community in time
        - Website/newsgroup
    - Product package
        - Modem
        - Antenna & cables
        - PC/modem antenna
        - CD with drivers / documentation
    - QC
        - What is "standard" data & products?
        - Data not released until QC'd
        - How, who?
- Data Management and Communications – IOOS plan
    - Documented
    - Covers real-time distributed data
- Iridium system like ARGOS?
- Everyone doing this differently
- Just tell us where to send it
- Service provider
    - Will provider use all protocols
        - PPP
        - Z-modem, etc.
    - Bi-directional access
    - Reliability
    - Interface documentation
    - Access to technical support
        - Where is the problem?
        - Open communication
        - Defined flow of support
            - Iridium tiers of technical ownership
            - Single point of support
                - Web site monitored by all tiers
        - Funding
            - Stakeholders
            - Political issue
                - Existing data repository ownership
                - Metadata definition
- Housekeeping/engineering vs. scientific data
    - Error checking
    - Transmission/data integrity
        - Should there be community QC?
        - What form should it be in?
        - Done where
            - Gateway?
            - Final destination?

            - End user?
        - What exists in Iridium system already?
            - Documented
            - Is it possible to use an existing mechanism to report to the buoy/shore that the data arrived fully?
        - Forward Error Correction
            - Maybe, but no documentation available
                - It looks like it
                - No official answer
                - Talk to General Dynamics
                    - Engineers not available for questions
- Rate structure
    - Where is it going?
    - Free air time critical for further development
        - Allows more time to debug systems
        - Significant systems deployed using Iridium as a direct result
    - Suppliers
    - List of equipment/resellers
- Communications from suppliers
    - How to get information from them without asking for it
    - "Prototype" aspect of 9500 not communicated
    - Interim designs
- Uncertainty
- Daytona vs. next model
- No difference in serial ports
- List of items for next year's meeting
    - When would we want to meet again in a similar workshop forum

PROBLEMS/ISSUES/RECOMMENDATIONS

While Workshop participants agreed that Iridium provides a much needed global and real time data communications capability, a number of problems and issues were identified.

The primary issues addressed relate to establishing a mechanism to support the introduction and use of Iridium data communication and training. The lack of a formalized means to capture, compile, and document and share critical information was identified as a key issue by each Working Group. As noted in other sections of this report, many of the problems addressed during the Workshop briefings had been previously identified and corrected. Improvements in the hardware and software in the 9505 Iridium phone and data modem corrected the self-initiated internal power-down, signal fluctuations, and UART lock problems. The firmware for the Data-After-Voice

(DAV) capability was also corrected. Newer software versions allow the user to accurately profile signal strength. It was noted, however, that this information was not readily available to those implementing Iridium data communication. The concept of establishing a mechanism for providing support and disseminating information was strongly supported by Workshop participants. Participants agreed that this support system would include a repository of information that address what works and what doesn't work. For example, it was noted that the Apollo Emulator will not work with Linux and a number of attendees noted significant problems exist with Kermit that probably contributed to poor transmission success rates. The support system should include lessons learned, and list hardware and firmware versions, related bugs and corrections/work-arounds. Information on new Iridium services would be included, along with hardware and protocol documentation. Other information addressed would include:

- Who do we contact?
- Information on antenna types, uses, considerations and placement
  - Assistance in selecting an antenna for a particular application
  - Information on antenna covering/obstruction material transparency
  - Radiation patterns
  - Work-arounds for the Iridium modem 3db RF signal loss limit
- A standardized 'form' or procedure to assist the user in asking the right question
- An alert system was addressed that would notify current Iridium users concerning hardware/firmware/software upgrades, and specific information about the procedures to be followed in getting access to them.
- Web-based user support links
  - On line access to individual SIM call logs
- Existing success stories
- Self-help tools
- Summary by service providers of comment/lessons learned into FAQs
- USENET newsgroup
- WIKI

        - Set of user modifiable web pages
            - Growing community maintained website
    - Standardized libraries for embedded platforms

A related issue addressed is how such support should be structured, who will provide it and who will fund it. Attendees noted similar support problems existed with Argos during the mid-eighties, with the Data Buoy Cooperation Panel (DBCP) being initially contacted for support and the later successful introduction of a technical coordinator based at Argos Toulouse. Options addressed included following the Argos model, with a coordinator funded and reporting to the user community. It was suggested that a central coordinator/Ocean advocate be established, possibly within Iridium Satellite LLC or some other office with connectivity to the Global Telecommunications System. The coordinator could come from a non-profit entity that supports research and operational (non-profit) users, or from a non-profit SP (Service Provider), if such an organization was formed. One Working Group suggested the coordinator come from the community of users. Regardless of the source, a high level of technical expertise will be required, much of which resides with the VAMs (Value-Added Manufacturers) and SPs, in widely varying levels. In this regard, vendors should be capable of providing out of the box product support.

It was the consensus that funding be provided by the community of users. The question was poised, which of the governing bodies should decide the funding issue? While no clear answer existed, one suggestion was that Ocean.US lead the coordination issue with the governing bodies.

The Iridium rate structure was also addressed. How will it be structured in the future? How do we determine and compare costs associated with SIM (Subscriber Identity Module) card activation, monthly charges for various services, etc., between various providers? Is there a list of airtime providers and a matrix comparing costs? This is an issue that could fall within the purview of the support structure once established.

Another issue raised is the level of support required. One Working Group stated 24/7 support should be available for Search and Rescue and other safety-related requirements, while another believed that a response within 24 hours would be acceptable. E-mail support should be available in support of developers. It was agreed that information should be pushed to the users, although it not determine who would originate such information.

Several of the issues had legal implications. One was the ownership rights to the existing data repository. In addition, it was suggested on a number of occasions during Technical Workshop that source code be made available to developers. However, it was also noted that much of this source code is proprietary.

A number of recommendations were made on hardware improvement. It was noted that the VAMs/SPs are not impartial, and that the support system to be established should act as the impartial source of information. Hardware recommendations include:

- Self-test mode in future modems.
- Priority rating for specific units to support SAR missions and other safety-related missions.
- Users of Short-Burst Data (SBD) should be able to request Iridium registration information by e-Mail to include date/time and location to track units without needing sophisticated protocols. (Note: SBD allows the user to register up to 5 e-Mail addresses to receive time/location data for the modem with GPS)
- SIM card holder with a foam type substance that would better secure the card in the SIM holder
- Nitrogen purged/vacuum/pressurized case
- Further ruggidization (industrial vice commercial)
- Multi-channel modem (4 L-Band Transceivers) as a standard product to replace Inmarsat on ships
- Smaller, cheaper, faster modems (Note: The 9600 Short Burst Data-only modem is now being developed. It will be much smaller and significantly cheaper but will not increase throughput)

The self-test features and product modifications/packaging, to include the SIM card holder with foam, industrial ruggidization and nitrogen purged/vacuum/ pressurized cases can be accomplished.

Software recommendations included development of a Soft-SIM, enhanced security capabilities and software that will work with Linux. It was recommended that a compression capability be developed independent of the Apollo Emulator. .

Development of a training program was also identified as a critical requirement. It was recommended that such training be provided by Iridium and NAL Research, and be tailored for the oceanographic community. How often to schedule training and how large a class should be formed was a topic of discussion. It was unclear what organization will lead the effort to coordinate an Iridium training class.

An issue that was discussed by each of the Working Groups was how to QC and distribute standard data products. It was noted that this activity is application related. Questions raised include:

- Real-time vs. database?
- Free access or subscription?
- Who should provide service?
- Who should fund service?
- What is "standard" data and products?
- Who QCs data prior to release?

CONCLUSION

The Technical Workshop provided a much needed forum for our community to share successes, shortfalls, frustrations and lessons learned in implementing Iridium data communications. Significant differences in hardware, firmware and supporting software used by Workshop attendees were evident, and resulted in numerous and valuable lessons learned. Iridium Satellite LLC and NAL Research were available to answer technical questions, and to outline improvements made to the 9505 generation Iridium hardware and software/firmware to correct many of the problems noted. Iridium data communication capabilities, such as SBD and RUDICS, were also addressed.

Users embraced significant improvements in Iridium coverage, latency and data rates as compared to the Argos system. Working Groups were able to articulate problems and issues that require consideration, and formulate suggestions for further evaluation and/or implementation. The primary issues addressed the establishment of a structure to provide support for the introduction and use of Iridium data communication, and the development of a training program. The lack of a formalized means to capture, compile, and document and share critical information was addressed throughout the Workshop. Attendees strongly agree that a repository of Iridium information is needed, and that web based and live technical support is needed. The consensus calls for establishment of a central coordinator/Ocean advocate similar to that established in support of the Argo system. As outlined in the Problems/Issues/Recommendation section of this report, how such support should be structured, who will provide it and who will fund it, were discussed at length, with a number of options proposed.

The second major issue involved developing an Iridium training program tailored for the oceanographic community. Ocean.US will take the lead in coordinating with Iridium Satellite LLC and NAL Research to develop and conduct user training.

The Workshop was most successful in providing a means for sharing critical user information related to the use of Iridium telecommunications in support of a myriad of applications. It brought together the technical expertise and community of users to articulate successes and failures, and to collectively document issues and recommendations for the successful implementation of Iridium data communication. The findings of the Workshop will form the baseline for the evaluation of future requirements and courses of action.

ACRONYMS

Acronym	Meaning
ADEOS	Advanced Earth Orbiting Satellite
AIS	Automated Identification System
AMSR	Advanced Microwave Scanning Radiometer
AWSs	Automatic Weather Stations
BGAN	Global Area Network
CONUS	Continental United States
COOS	Coastal Ocean Observing System
COPRI	Coasts, Oceans, Ports and Rivers Institute
COSEE	Center for Ocean Science Education Excellence
DAV	The Data-After-Voice
dB	decibel
DBCP	Data Buoy Co-operation Panel
DE-BPSK	Differential Encoded Binary Phase Shift Keying
DE-QPSK	Differentially Encoded Quaternary Phase Shift Keying
DSN	Defense Switched Network
EPA	Environmental Protection Agency
FDMA/TDMA	Frequency Division Multiple Access/Time Division Multiple Access
GLI	Global Imager
GOES	Geostationary Operational Environmental Satellite
GoMOOS	Gulf of Maine Ocean Observing System
GSM	Global System for Mobile Communications
HERF	Hazardous Electromagnetic Radiation to Fuel
HERO	Hazardous Electromagnetic Radiation to Ordnance
IGO	InterGovernmental Organization
IMEI	International Mobile Equipment Identity
IMSO	International Mobile Satellite Organization
IOOS	Integrated Ocean Observing System
ISL	Inter-Satellite Links
ISLLC	Iridium Satellite LLC
ISU	Iridium Subscriber Unit
IT	Information Technology
JAXA	Japan Aerospace Exploration Agency
LEO	Low-Earth Orbit
LES	Land Earth Station
MBARI	Monterey Bay Aquarium Research Institute
METOP	Meteorological Operational satellite
MOOS	MBARI Ocean Observing System
MXU	MultipleXer Unit
NASA	National Aeronautics and Space Administration
NC-COOS	North Carolina Coastal Ocean Observing System
NESDIS	National Environmental Satellite Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NSF	National Science Foundation
ONR	Office of Naval Research
ORION	Ocean Research Interactive Observatory Networks
PENGUIn	Polar Experiment Network for Geophysical Upper-Atmosphere Investigations

PICO	Platform and Instrumentation for Continuous Ocean Observations
PMEL	Pacific Marine Environmental Laboratory
PPP	Point to Point Protocol
pppd	Point-to-Point Protocol daemon
PPTP	Point-to-Point Tunneling Protocol,
PRISM	Polar Radar for Ice Sheet Measurement
PSDK	Spectral Flux Density
PSTN	Public Switched Telephone Network
PTT	Platform Transmitter Terminal
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RF	Radio Frequency
RUDICS	Router-based Unstructured Digital Inter-Working Connectivity Solution
SBD	Short Burst Data
SBIR	Small Business Innovative Research
SIM	Subscriber Identity Module
SMS	Short Messaging Service
SNCO	Satellite Network Operations Center
SOC	Southampton Oceanography Center
SP	Service Providers
SSC	Satellite Control Center
TCP/IP	Transmission Control Protocol/Internet Protocol
TIROS	Television and Infrared Observation Satellite
TOS	The Oceanography Society
UART	Universal Asynchronous Receiver Transmitter
USCG	United States Coast Guard
USGS	United States Geological Survey
VAMs	Value-Added Manufacturers

Appendix F Iridium Satellite Data Services White Paper

IRIDIUM

Iridium Satellite Data Services White Paper

Version 1.0
June 2nd 2003

Purpose:

This document describes Iridium Satellite's current data services. The objective is to provide an overview of the Iridium satellite network, hardware and data services to aid in the selection of an appropriate data service for a particular integrated data application. This document does not contain detailed technical information.

Scope:

This white paper covers the following areas

- Iridium Satellite Network
- Iridium Hardware
- Iridium Dial-Up Data
- Iridium Direct Internet
- Iridium Router Based UDI Connectivity Solution [RUDICS]
- Iridium Short Burst Data (SBD)
- Iridium Short Message Service (SMS)

This paper provides basic system information and parameters; it does not contain a detailed technical description of each service. This paper assumes a reasonable knowledge of data, telephony and satellite communications.

Iridium Satellite Network Overview

The Iridium System is a satellite-based, wireless communications network providing a robust suite of data services to virtually any destination anywhere on earth. The Iridium system comprises three principal components: the satellite network, the ground network and the Iridium subscriber products including phones and pagers. The design of the Iridium network allows data to be routed virtually anywhere in the world. Data calls are relayed from one satellite to another until they reach the satellite above the Iridium Subscriber Unit and the signal is relayed back to Earth.

The on-orbit Iridium constellation consists of 66 operational satellites and 14 spares in a constellation of six polar planes. Each plane has 11 mission satellites performing as nodes in the telephony network. The 14 additional satellites orbit as spares ready to replace any unserviceable satellite. This constellation ensures that every region on the globe is covered by at least one satellite at all times. The satellites are in a near-polar orbit at an altitude of 485 miles (780 km). They circle the earth once every 100 minutes traveling at a rate of 16,832 miles per hour. Each satellite is cross-linked to four other satellites; two satellites in the same orbital plane and two in an adjacent plane. The satellite constellation is expected to provide continuous global coverage until 2014.

The ground network is comprised of the System Control Segment and gateways used to connect into the terrestrial data networks. The System Control Segment is the central management component for the Iridium system. It provides global operational support and control services for the satellite constellation and delivers satellite tracking data to the gateways. The System Control Segment consists of three main components: Four Telemetry Tracking and Control sites, the Operational Support Network, and the Satellite Network Operation Center. The primary linkage between the System Control Segment, the satellites, and the gateways is via K-Band feeder links and cross-links throughout the satellite constellation.

Gateways are the terrestrial infrastructure that provides interconnection to the terrestrial data networks. Gateways also provide network management functions for their own network elements and links.

Iridium Satellite LLC Distribution Channels

Iridium has established a number of distribution channels for its services and products. The intent with each channel is to maximize either the distribution of existing products and services or to enable products and services to be integrated into specific vertical market applications. Specific descriptions of each channel are included below. Information on how to contact a distribution partner of the Iridium can be found on the Iridium web site at http://www.iridium.com.

Iridium Service Partner (SP)

SPs typically sell Iridium products and services through a distribution channel that encompasses both regional and vertical market attributes. SP's typically sell handsets or specific vertical market implementations of handsets (e.g. a maritime or aviation version) along with voice and basic circuit switched data services.

Iridium Value Added Reseller (VAR)

VARs incorporate a specific Iridium Subscriber Unit and service into a complete end to end solution for a particular customer or vertical market. A VAR is a company that provides a total wireless data solution for an end customer. They integrate all hardware and software for both the remote device as well as the back office/host computer system. VARs also directly sell Iridium Satellite Data Services with their solution. Iridium directly supports Iridium VARs with technical information.

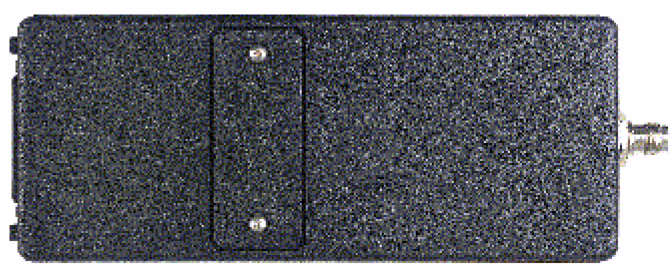
Iridium VARs are selected based upon experience, a repeatable business case and other factors.

Iridium Value Added Manufacturer (VAM)

A VAM is a company that has particular expertise in a vertical market and wishes to integrate an Iridium voice or data module into a finished or OEM product. VAMs do not resell voice or data services directly from Iridium. Iridium directly supports VAMs with technical information.

Iridium Hardware

The Motorola Satellite Series 9522 L-Band Transceiver (LBT) is intended for incorporation into an integrated data solution or product. The LBT is simply the core modem that is required in order to communicate over the Iridium network. Additional components are required such as power supply, antenna, environmental protection and the serial based interface between the LBT and the customer's application.



The LBT provides two interfaces for data applications. A TNC connector is provided for the RF connection to the antenna. A DB25 connector is provided for power, on/off control and a RS232 port.

Basic Specifications:

Dimensions	Value
Length (including antenna connector)	216.1 mm (8.51")
Length (excluding antenna connector)	196.4 mm (7.73")
Width	82.6 mm (3.25")
Depth	39.0 mm (1.54")
Weight (approximate)	610 g

DC Power Input Specifications	Value
Main Input Voltage - Range	+4.0 VDC to +4.8 VDC
Main Input Voltage - Nominal	4.4 VDC
Main Input Voltage - Ripple	40 mVpp
Peak Input Current (maximum)	2.5 A @ 4.4 VDC
Main Input Active Power (average)	2500 mW
Main Input Standby Power (average)	210 mW

Iridium Dial-Up Data Service

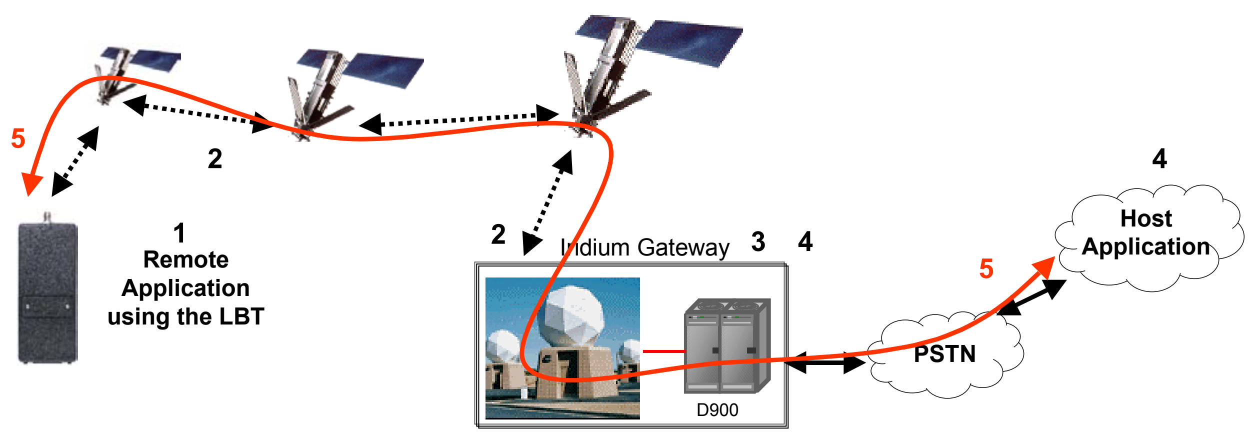
Service Description

Iridium Dial-Up Data Service is an asynchronous, circuit switched, 2400 bits per second, bi-directional service. Data calls can be originated:

- From an Iridium Subscriber Unit (ISU) to the Public Switched Telephone Network (PSTN) as shown in Figure 1
- From the PSTN to an ISU as shown in Figure 1
- From one ISU to another ISU as shown in Figure 2

An RS232C interface with AT Commands is used for making a data call. Data connections to the PSTN operate at 2400 bits per second. Terminating PSTN modems should be configured to start negotiating at 4800bps in order to minimize modem negotiation time. A document detailing the AT Commands is available to authorized developers.

Figure 1
A Circuit Switched Data Call from a remote application (ISU) to the PSTN.

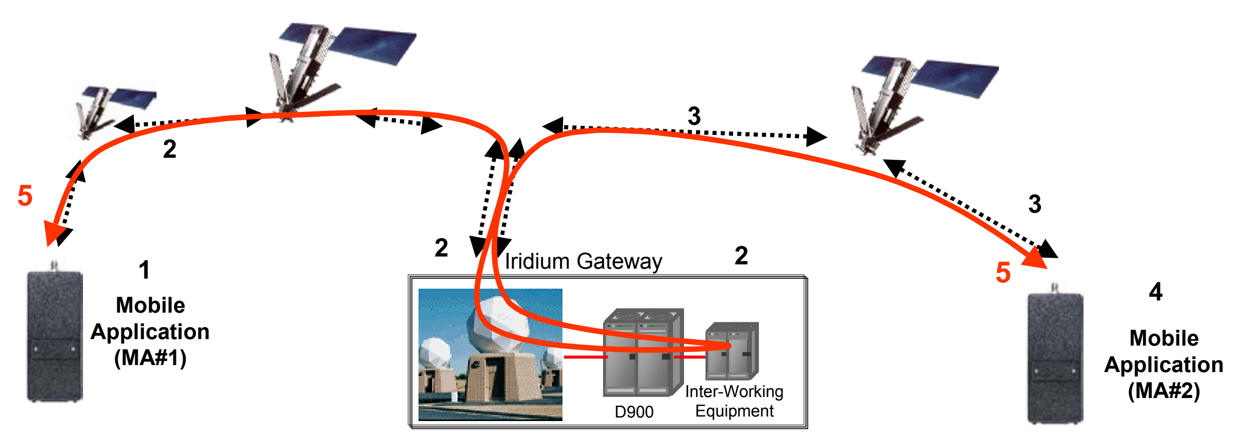


Sequence of Events:

1. Application dials number on PSTN using AT Commands (e.g. 0044171……)
2. Call request is routed over the constellation for user authentication and call set-up (~5 sec)
3. Switch makes connection to dialed number (~5 sec)
4. Analog modem in gateway and analog modem in host application synchronize (~30 sec).
5. End-to-End connection established, over the constellation, between the Host Application and Mobile Application

Note that it is also possible to for the Host Application to initiate the call to the remote application by dialing the MSISDN-C of the remote application beginning with the International dialing prefix followed by the Iridium Country code number (8816) and the eight digit number.

Figure 2
A Circuit Switched Data Call between two ISUs.



Sequence of Events:

1. Mobile Application #1 dials MSISDN or MSISDN-C of MA#2
2. MA#1 call is set-up and connected to inter-working equipment
3. Ring alert and call set-up issued by gateway to MA#2
4. MA#2 answers incoming call request (total set-up ~25 sec)
5. End-to-End connection established between MA#1 & MA#2

Dial-Up Data Applications

Dial-up data is suitable for applications that require direct computer-to-computer or device-to-device connections. Each device or computer should be connected to a PSTN modem or an ISU.

Sample applications for this type of service include:

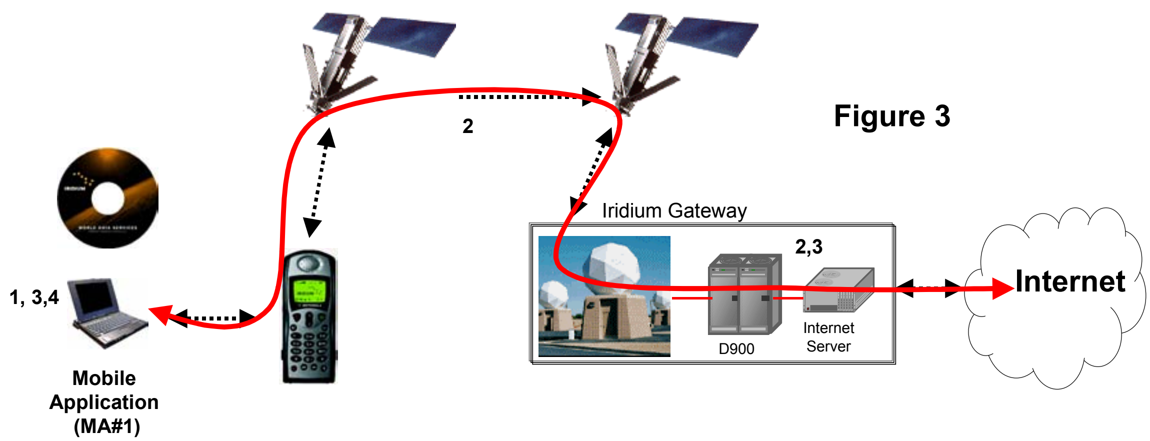
- Connecting Remote Terminal Units (RTUs) to central control and monitoring systems.
- Connecting monitoring equipment to central data collection systems.
- Continuous real time transfer of data.
- Dialing into an Internet Service Provider.
- Dialing into a LAN (Local Area Network.)

Iridium Direct Internet Service

Service Description

Direct Internet is a service that allows a subscriber with a Windows-based computer to access the Internet over the Iridium network using an optimized circuit switched data channel. If the destination computer is a computer connected to the Internet and has an Internet Protocol (IP) address then the Iridium Direct Internet Service is usually the best option if the remote user is using a standard Windows based operating system.

Figure 3
A Direct Internet Data Call from a remote application (ISU) to the Internet.



Sequence of Events:

1. MA#1 client Direct Internet Software dials the number for the Direct Internet Server
2. MA#1 call is set-up and connected to the Direct Internet Server
3. MA#1 negotiates connection protocol and authenticates with Direct Internet Server (~ 12 seconds)
4. Standard Internet applications software can then access the Internet

Direct Internet uses “on-the-fly” data compression to increase the effective data throughput. The compression ratio depends on the type of data being sent or received; text is highly compressible whereas JPEG graphics files are not compressible. Although the underlying channel rate is 2400bps, the effective throughput can reach 10,000bps. Direct Internet connections can only be originated from an ISU. Connections to an ISU cannot be originated from the Internet. Figure 3 illustrates the call path.

Direct Internet software is compatible with many applications that work under Windows Dial-Up Networking. An additional feature of Direct Internet is that it can automatically terminate the airtime call if no data traffic has been sent or received within a user specified window. This is called spoofing. Currently supported Windows versions include Windows 95, 98, NT4.0, Me, 2000 and XP. SmartConnect is a feature that will automatically re-establish a dropped call and resume data transfer at the point where the transfer had terminated. .

Direct Internet Service Applications

Typical applications include:

- Email – Send and receive email using Outlook, Eudora or other email client
- FTP (File Transfer Protocol) for transferring data files.
- Web browsing – primarily on text based sites.
- Telnet sessions

Note that additional configuration may be required in order to optimize the throughput of any particular application.

Iridium Point-to-Point Protocol (PPP) Service

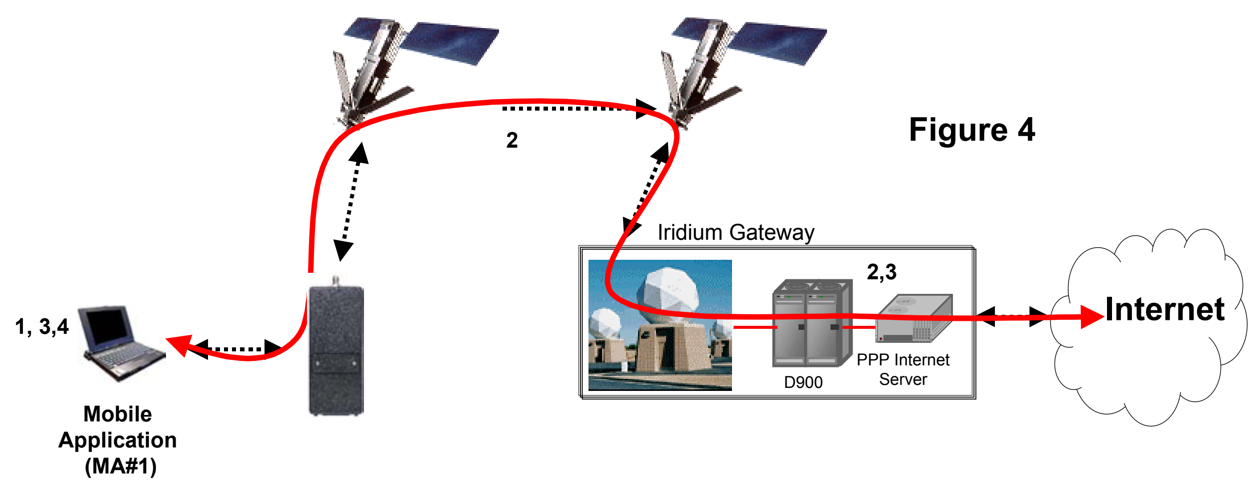
Service Description

PPP is essentially a hybrid between the Direct Internet Data service and the Dial-Up Data service. The user sets up a standard Dial-Up Networking connection that dials directly into the Direct Internet server, thus eliminating the analog modems required in a PSTN connection. Since PPP does not utilize the Direct Internet software, it does not provide the enhancements of Spoofing, SmartConnect or compression. The advantage of this service is that you have the stability of a Direct Internet call without having to load the Direct Internet software on the client side. Set-up times of calls are reduced and the percentage of established calls is significantly higher than using the PSTN to connect to an ISP.

This service only works when a call is originated by an ISU to the PPP server in the gateway. The PPP server cannot call the ISU. The ISU is not assigned an IP address. Figure 4 illustrates the call path.

PPP service is designed for use in applications where a computing device needs to connect to a computer via to the Internet. Direct Internet relies on software that only supports Windows operating systems. Third party PPP protocol software is available from other sources for many computing platforms and devices. Note that Iridium only provides limited support for use of the PPP Service.

Figure 4
A PPP Data Call from a remote application (ISU) to the Internet.



Sequence of Events:

1. MA#1 dials the number for the PPP Server
2. MA#1 call is set-up and connected to the PPP Server
3. MA#1 negotiates the PPP connection protocol
4. Standard Internet applications software can then access the Internet via the TCP/IP stack

PPP Service Applications

Iridium PPP service is designed to serve two types of applications:

1) Direct connection to the Internet for non-Windows based computing platforms. Linux, Apple, Palm and other operating systems can be configured to use a PPP client for communication to the Internet. [Windows based applications should use Iridium Direct Internet Service.]
2) Application specific data communications for telemetry, remote monitoring or tracking of field based assets.

Non-Windows based systems, with typical applications utilizing the Internet, include email, file transfer, telnet and other terminal sessions. PPP service allows connection to any publicly available IP address on the Internet.

For specific applications, this service could be used with an Iridium 9522 L-Band Transceiver in an integrated application. An applications developer could integrate the service and hardware to provide data connectivity from a remote or mobile application to an IP address over the Iridium network.

Iridium Router based Unrestricted Digital Interworking Connectivity Solution [RUDICS]

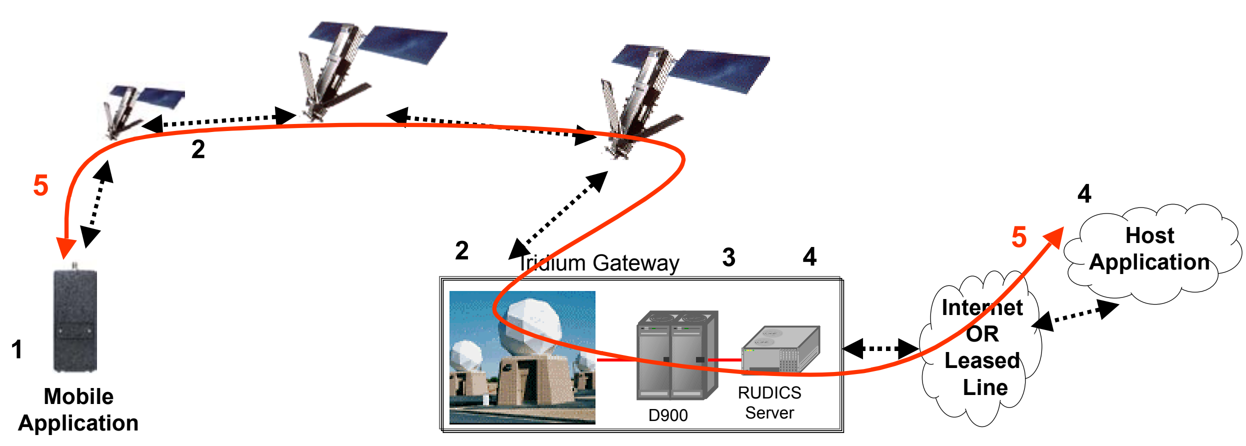
Service Description

RUDICS is a circuit switched data service designed to be incorporated into an integrated data solution. Integrated data solutions are applications such as remote asset monitoring, control, and data file transfer. Often these applications are designed to support hundreds or thousands of remote units. The other circuit switched data services mentioned in this paper are sometimes sub-optimal for such applications. RUDICS is designed to take advantage of the global nature of the Iridium communications system and combine that with a modern digital connection between the Iridium Gateway and the Value Added Resellers centralized application server or Host Application.

RUDICS uses the same circuit switched data service that is described in the sections on “Dial-Up Data” and Direct Internet. The difference and key benefit comes in the equipment used to terminate or originate the call in the Iridium Gateway.

Figure 5 illustrates the call path for a Mobile Originated call.

Figure 5
A RUDICS Data Call from a remote application (ISU) to the central Host Application

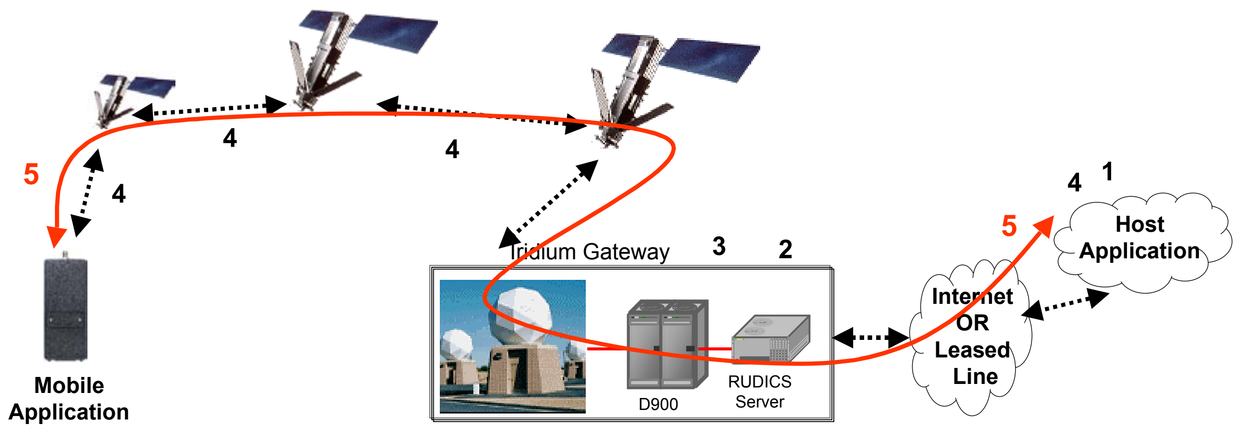


Sequence of Events:

1. Mobile application places call to a custom RUDICS Server Number
2. Call request is routed over the constellation for user authentication and call set-up.
3. Switch connects to RUDICS Server, secondary authentication conducted
4. RUDICS Server terminates call to pre-configured IP Address
5. End-to-End IP connection established, over the constellation, between the Host Application and Mobile Application

Figure 6 illustrates the call path for a Mobile Terminated call.

Figure 6
A RUDICS Data Call from a central Host Application to the remote application (ISU).



Sequence of Events:

1. Host application places telnet call to RUDICS Server
2. RUDICS Server Authenticates Host
3. Call request is routed to the switch for call set-up
4. Call request is routed over the constellation for user authentication and call set-up.
5. Mobile Application answers call. End-to-End IP connection established, over the constellation, between the Host Application and Mobile Application

RUDICS uses routers to allow termination and origination of circuit switched data calls to and from a specific IP address via a Telnet protocol. The capability is designed to support applications that have many field devices and one central host application. The service allows field devices to directly call the host application and the host application is able to directly call the field devices.

Connectivity between the Iridium Gateway and the Host Application can be by a variety of methods, including Internet, Virtual Private Network and Leased Line

RUDICS has a number of advantages over other methods of originating and terminating Circuit Switched Data calls on Iridium. The following table describes some of these advantages:

Service Type	Limitation	RUDICS Advantage
Dial Up Data	Analog modem training time	No modem training time and therefore lower cost per call
Dial Up Data	PSTN origination fee set by long distance or international carrier	Service rates are identical for Mobile Originated or Mobile Terminated calls
Direct Internet	Remote unit must initiate session. Unit cannot be called directly from an IP Address	Calls can be Mobile Originated and Mobile Terminated
Direct Internet	Requires Windows Operating System	No Operating System requirement
Direct Internet	Remote unit IP address is non-routable	Routable IP addresses.
Direct Internet	TCP/IP Stack negotiation uses billable airtime	Application vendor can select appropriate protocol
PPP Service	Requires TCP/IP Stack	No TCP/IP Stack Required
PPP Service	Remote unit must initiate session. Unit cannot be called directly from an IP Address	Calls can be Mobile Originated and Mobile Terminated
PPP Service	Remote unit IP address is non-routable	Routable IP addresses.
PPP Service	TCP/IP Stack negotiation uses billable airtime	Application vendor can select appropriate protocol

RUDICS Service Applications

Typical applications include:

- Email – Sending and receiving of email using custom applications software
- FTP (File Transfer Protocol) for transferring data files.
- Periodic data reporting by remote sensors
- Polling of remote units to collect data
- Control of remote equipment

Note that RUDICS is typically best suited for applications that deploy more than 500 units, which report to a central host application.

Iridium Short Burst Data (SBD) Service

Service Description

Iridium Short Burst Data (SBD) Service is an efficient network protocol designed for shorter sized data messages than can be economically sent via Iridium Circuit Switched Data Services. SBD uses a proprietary network protocol to transfer data messages to and from the remote terminal. An overview is shown in Figure 7.

It is possible to send Mobile Originated (MO-SBD) and Mobile Terminated (MT-SBD) messages. Message size for MO-SBD is between 1 and 1960 bytes. (0 byte messages are referred to as “mailbox checks.”) Message size for MT-SBD is between 1 and 1890 bytes.

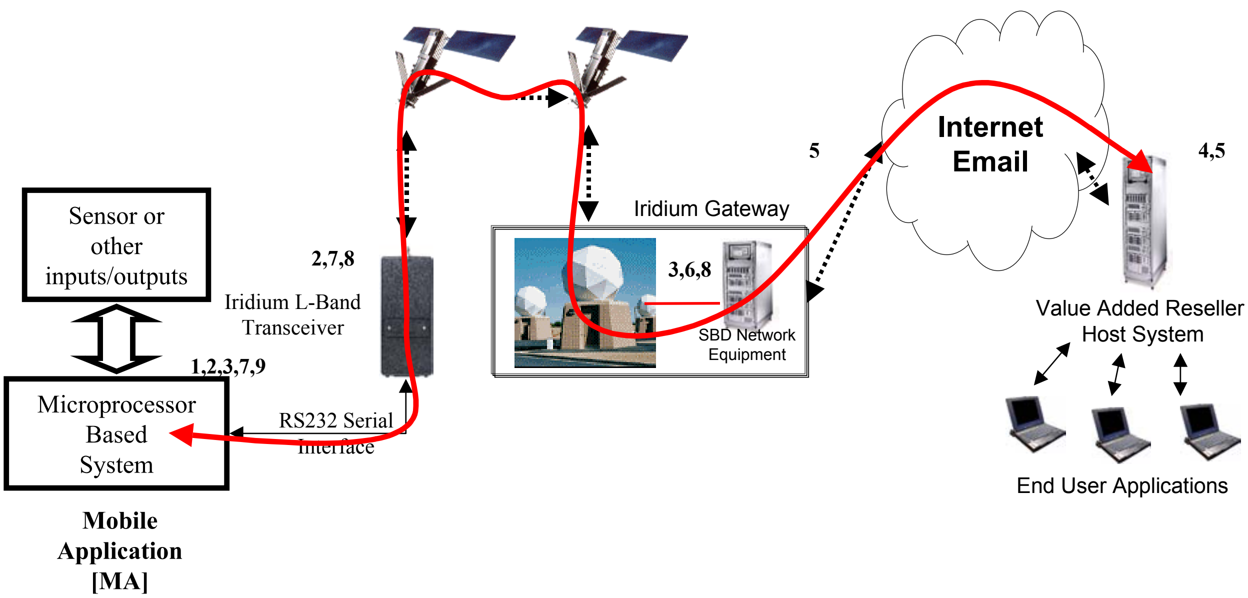
The target vertical markets for SBD are Oil, Gas, Rail, Maritime, Aeronautical, and Utility industries as well as applications in the Government and Military sectors. Iridium itself does not provide complete end-to-end solutions. However, it looks to selectively partner with skilled Value Added Resellers (VARs) to integrate the required hardware, software, and SBD service that ultimately forms the complete packaged solution for the end customer.

Remote Applications send Mobile Originated SBD (MO-SBD) data messages via an Iridium 9522 L-Band Transceiver (“LBT”). The application microcontroller or microprocessor communicates with the LBT using AT commands over an RS232 serial port. The application loads the data message into the LBT and instructs it to send the data message. The data message is transmitted across the Iridium satellite network utilizing inter-satellite links to reach the Iridium Gateway. From there the data message is transferred via e-mail to the VARs host computer system. Here the message is stored in a database for further data processing.

Mobile Terminated SBD (MT-SBD) messages are sent to the Iridium Gateway via e-mail from the VARs host computer system. MT-SBD data messages are delivered to the LBT following a MO-SBD or “mail-box check” initiated by the remote application.

The maximum length of a MO-SBD message is 1960 bytes. The maximum length of a MT-SBD message is 1890 bytes. Global network transmit latency for delivery of messages ranges from approximately 5 seconds for short messages to approximately 20 seconds for maximum length messages. This latency is the elapsed time before the Iridium SBD system sends the SBD message to its email destination. Additional latency introduced by the Internet or the customer’s host system is not in Iridium’s control.

Figure 7
A SBD Data Call from a remote application (ISU) to the Internet.



Sequence of Events: MO-SBD

1. MA loads the MO-SBD data message into the L-Band Transceiver.
2. MA instructs the L-Band Transceiver to send the SBD Message to the Iridium Gateway
3. Iridium Gateway SBD Equipment receives the SBD Message; sends an acknowledgement to the MA and creates an email message with the SBD data message as an attachment to the email.
4. Email message is sent to the destination email server hosted by the Value Added Reseller for processing of the data message.

Sequence of Events: MT-SBD

5. Email message is sent to the Iridium Gateway server by the Value Added Reseller's Host Server.
6. Iridium Gateway SBD Equipment receives the MT-SBD Message and stores it in a database.
7. The MA initiates a "Mailbox Check" and the MT-SBD Message is downloaded to the L-Band Transceiver.
8. The L-Band Transceiver sends an acknowledgement to the Iridium Gateway that the MT-SBD Message has been delivered.
9. MA extracts the MT-SBD Message from the L-Band Transceiver and processes the message.

Iridium SBD Service Applications

Iridium SBD Service is designed to serve a range of applications that need to send data messages that on average are typically less than 300 bytes.

Specific applications may include:

- Flight following for aircraft and helicopters
- Tracking and messaging for maritime vessels
- Tracking of mobile land based assets such as trucks and heavy equipment
- Monitoring of equipment on oil and gas pipelines
- Monitoring of equipment of water, gas and electric utility distribution networks

Iridium Short Message Service (SMS)

Service Description

Short Message Service is a GSM based system capability designed for both Mobile Origination (MO) and Mobile Termination (MT) of short text messages. There are numerous GSM-SMS applications developed for terrestrial GSM networks. It should be possible to adapt existing terrestrial based applications and also develop new applications using the Iridium SMS service.

The Iridium SMS service offers the following capabilities:

- Two-way global text messaging.
- Send to and receive from other Iridium SMS subscribers.
- Send to and receive from email addresses. Iridium subscribers are able to receive SMS messages via <MSISDN>@msg.iridium.com, where <MSISDN> is the Iridium phone number.
- Send to and receive from cellular subscribers (when available.)
- 160 characters per message.
- Messages will be stored until delivered (up to 8 days.)
- Supported on 9505 handsets and 9522 LBTs with SMS capable firmware.
  - SMS messages can be entered into the phone in one of two ways:
    - Via the phone's keypad
    - Via the phone's data port, using standard AT commands

Iridium SMS Service Applications

The Iridium SMS Service can be used to serve a range of applications that can send useful information within the 160-character limit of each message.

Specific applications may include:

- Weather information & alerts
- Schedule information
- News & Sports information
- Personal messaging
- Basic email messaging
- Monitoring of remote applications

- ## Choosing A Data Service

There are many reasons that a particular data service may be chosen. The purpose of the table below is to assist in narrowing down the choices and is not an exhaustive selection matrix. In addition to technical details, commercial information such as the usage profile and service pricing is also required in order to determine the most appropriate data service.

Service Name	Typical Use	Transfer Type
Direct Internet	Remote access to Internet based personal email service using a Windows based computer	Human to Machine
Dial-Up Data	Remote access to a corporate email service not connected to the Internet	Human to Machine
PPP Service	Access to the Internet by a computer without a Windows Operating System	Human to Machine
RUDICS Short Burst Data	Large scale monitoring of fixed or mobile assets beyond typical terrestrial coverage	Machine to Machine
Direct Internet Dial-Up Data RUDICS	File transfers that typically are 500 bytes or more per transfer	Machine to Machine
Short Burst Data	File transfers that typically are less than 500 bytes per transfer	Machine to Machine
Short Burst Data	Frequent short file transfers [Less than 500 bytes]	Machine to Machine
RUDICS Short Burst Data	Integrated data applications	Machine to Machine
Direct Internet Dial-Up Data PPP	General ad-hoc file transfer [Human to Machine]	Human to Machine
Short Message Service	Send or receive short email (text message)	Human to Human