# REAL-TIME TELEMETRY OPTIONS FOR OCEAN OBSERVING SYSTEMS

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## ABSTRACT

**Abstract**: Ocean observing systems provide a means to monitor oceanic variables on a variety of temporal and spatial scales. Data from ocean observing systems are most useful when they are collected in real-time; real-time data allow the detection of important events as they occur. Various real-time telemetry options exist for transferring data from sea to shore and from the subsurface to the surface. We survey these telemetry options to highlight the research problems associated with subsea to surface to shore networking and include a comparison of existing real-time technologies for three specific ocean observing system network topologies with respect to data transmission rates, power requirements, and cost. We conclude that cellular technology may prove to be the best means for sea to shore transmission in nearshore regions whereas Iridium satellite communications are ideal for locations not covered by cellular service. Further advances in cabled mooring lines and inductive and acoustic modem technologies will make these more attractive options for subsurface to surface data transmissions.

**Keywords:** real-time telemetry, ocean observing systems, Argos, Iridium, acoustic modem, inductive modem

## 1. Introduction

Ocean observing systems provide a means to monitor physical, biological, chemical, and geological properties of the water column and seafloor. The long term, sustained oceanographic data collected from observing platforms capture a broad range of oceanic variability and provide important information concerning episodic and periodic processes ranging in scale from minutes to years [1,2]. Ocean observing systems can be used to: monitor earthquakes for tsunami warnings, study and model water column physics for hurricane track predictions, measure hydrographic conditions for climate change studies, collect biological parameters for harmful algal bloom prediction and provide shellfish consumption warnings, and/or measure chemical parameters for beach pollutant warnings.

Data from ocean observing systems are most useful when they are provided in real-time. Real-time data allow scientists to detect important events (e.g., tsunamis, hurricanes and storms, eddies, harmful algal blooms, etc.) when they occur in order to respond appropriately, e.g., contact authorities to issue beach closure or shellfish consumption warnings and/or begin adaptive sampling (interrogating instruments to increase their sampling rate) to better understand ocean processes.

In this paper we first discuss different real-time telemetry options (section 2) to highlight the research problems associated with subsea to surface to shore networking. We then present specific examples of three types of ocean observing system topologies: shallow water moorings (section 3), deep-sea moorings (section 4), and moorings in conjunction with benthic platforms (section 5). In sections 3-5, we include a comparison of suitable real-time technologies with respect to data transmission rates, power requirements, and cost. In section 6, we discuss appropriate real-time telemetry solutions for each type of ocean observing system. We also present further improvements necessary for real-time technologies to make them more suitable for use on ocean observing systems.

## 2. Real-Time Telemetry

Undersea electrical and fiber-optic cables that connect moored sensors from surface to bottom to shore have proven to be robust and reliable data telemetry methods and can offer virtually unlimited power and bandwidth for data collection and transmission. However, implementation of undersea cables is quite expensive and extensive environmental permitting is required. Cabled moorings can have subsurface or surface buoys.

Other options for transmitting real-time data from moorings to shore are satellite, radio frequency (RF), and cell phone telemetry. These options all require a moored surface buoy and a method of transmitting data from depth to surface for sensors mounted along the mooring line (see below). Satellite systems are robust and reliable, with somewhat limited data rates. For example, Argos allows, on average 256 bytes per day per I.D. (depending on latitude) [3], traditional Iridium units offer roughly 2400 baud rate for transmission [4], and the Iridium short data burst (SBD) option transmits 205 bytes per connection [5]. Satellite communication costs can be quite expensive; rates are roughly $4000 per I.D. per year for Argos, $1 per minute for traditional Iridium, and $2 per kB for SDB Iridium. Argos systems are fairly power hungry and Iridium units are relatively low power; battery-operated deployments of up to one-year are possible with data transmissions scheduled for several times per day.

RF telemetry is virtually free of charge, (i.e. no costs associated with data transmission; costs are only associated with hardware), can support large amounts of data (115 kBps), and is relatively low power (roughly 500 mA for transmission, 100 mA for receiving) [6]. This type of data transmission requires line-of-sight between the mooring and an onshore receiving station (about 2-3 km distance between a small buoy and a receiving station at sea level) or a system of repeater stations within line-of-sight of one another and the data receiving station.

Cell phone technology is also geographically restricted. Moorings can only utilize this method in regions covered by cellular service. Costs associated with this type of data telemetry depend on the communication company plans. Cell phone data plans generally require a long-term contract (1-2 years), with a monthly service charge of roughly $40 to $90. Additionally, some companies may charge per kB or per minute data transmission. Data rates and power usage for cell phone technology are quite variable and are improving over time (e.g., 350-500 kBps through Sprint [7]).

Various methods of connecting sensors mounted along the mooring line to the surface for data transmission include: surface to bottom cable (i.e. hard-wire), acoustic modems, and inductive modems. Surface to bottom electro-optical-mechanical (EOM) cables are currently under development for high power (via solar and wind generators on the buoy) and data bandwidth from buoy to anchor. EOM cables are very expensive (rough estimate of $50-$100K) and can be susceptible to mechanical failure and breakage, especially in high seas [8]. Inexpensive communication cables can also be used to connect just a few sensors or sensor packages from near-surface to the buoy, thus reducing the chance of complete mooring failure. Communication cables offer virtually unlimited data rates but may suffer mechanical failure at connections between sensors.

Inductive modems also make use of a hard-wire along a mooring line for moderate data rates (1200 baud; 9600 baud in development) [9]. The cost of this solution depends on depth of transmission and the number of sensors on the mooring line. Although relatively easy to implement for simple moorings such as thermistor strings, inductive modems have been shown to fail at junctions, i.e. several bundles of sensors mounted on cages.

Acoustic modems can transfer real-time data wirelessly up a mooring line to a surface buoy. These systems are robust and offer data transmission rates of roughly 2400 – 19,200 baud [10], depending on transmission distance. At present, acoustic modems are difficult to interface with oceanographic sensors and can be quite power hungry (up to 40 W during transmission) and expensive ($5-$10K each).

### 3. Shallow Water Moorings

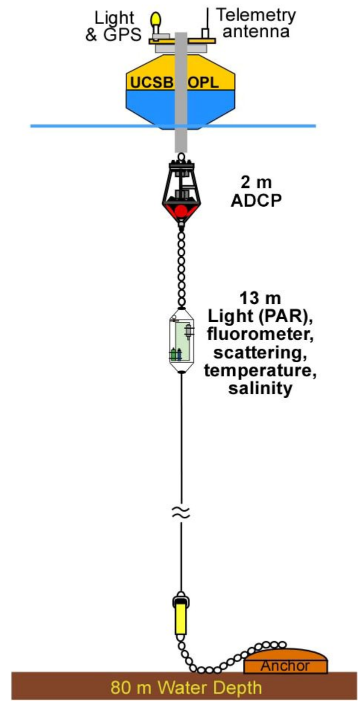


**Figure 1: Schematic diagram of the Southern California Coastal Ocean Observing System mooring, a shallow water mooring that produces 57,000 Bpd.**

We define a shallow water mooring as a mooring deployed in water depths of less than 300 m. Since shallow water moorings are often within close proximity to land, an undersea cable that connects the mooring, from surface to bottom, to an onshore station is a viable option, as well as most of the other real-time telemetry methods presented in section 2. RF and cell phone technology are, of course, dependent on mooring distance from shore.

An example of a shallow-water system is the Southern California Coastal Ocean Observing System (SCCOOS) mooring in the Santa Barbara Channel (Fig. 1). This mooring is located in 80 m water depth, 6 km from shore, and its suite of sensors produce 57,000 Bpd of data.

Possible data transmission rates for various telemetry options are provided in bytes per day (Bpd). Power estimates for these telemetry options are computed based on operating current values and baud rates provided in technical data sheets (inductive and acoustic modems) and empirical data obtained from laboratory tests (Argos, Iridium, and RF). These tests involve the monitoring of power usage and transmission time of a specific data sample. We show nominal power budgets that do not consider power usage due errors and data resends. Estimated yearly transmission costs, hardware costs and service charges are also included. Sea to shore telemetry budgets follow.

- Undersea cables: Unlimited data and power, >$2 million for hardware and implementation (laying cable, connectors, shore station, etc).
- Argos: 256 Bpd per I.D. (SCCOOS needs 223 I.D.s), 0.600 Ah/d for every 4 I.D.s (33.45 Ah/d), $890K transmission + $1500 hardware for every 4 I.D.s (= $83,600).
- Traditional Iridium: 50 MBpd, 0.042 Ah/d, $700 transmission + $1200 hardware + $600 service charge.
- SDB Iridium: >700,000 Bpd, 0.028 Ah/d, $41,700 transmission + $1200 hardware + $600 service charge.
- RF (one repeater station necessary): Virtually unlimited Bpd, 0.140 Ah/d per station, $1500 x 2 (= $3000) hardware + $5000 for repeater mooring.
- Cell phone: Virtually unlimited Bpd, 0.001 Ah/d, $200 hardware + $1000 service charge.

We now discuss methods of real-time data telemetry along a mooring line (i.e. from sensors at depth to surface buoy). Costs are associated with hardware only.

- EOM cable: Unlimited Bpd, no power, $5000.
- Communication cable: Unlimited Bpd, no power, $50.
- Inductive modem: 13 MBpd, 0.006 Ah/d, $8500.
- Acoustic modem: 26 MBpd, 0.018 Ah/d, $25,400.

## 4. Deep-Sea Moorings

Deep-sea moorings are typically deployed in regions far away from a landmass; hence RF and cell phone real-time data transmission technologies are infeasible. Undersea cables, although difficult to implement, are a possibility given the large number of retired communication cables spanning the globe. Satellite methods are more widely used for real-time data telemetry on deep-sea moorings. We present here, the Bermuda Testbed Mooring (BTM), located in over 4500 m water depth and 80 km from Bermuda in the Sargasso Sea, as an example of a deep-sea mooring (Fig. 2). Comparisons between each feasible real-time telemetry method for 302,800 Bpd of BTM data follow. [BTM power budgets are computed from SCCOOS power budgets, e.g., the BTM data rate is 5.3 times greater than that of SCCOOS, thus BTM power usage equals SCCOOS power usage multiplied by 5.3.]

- Undersea cables: Unlimited data and power, O($millions).
- Argos: 256 Bpd per I.D. (1183 I.D.s needed for BTM), 0.600 Ah/d for every 4 I.D.s (177.5 Ah/d), $4.7 million transmission + $1500 hardware for every 4 I.D.s (= $443,600).
- Traditional Iridium: 50 MBpd, 0.223 Ah/d, $2190 transmission + $1200 hardware + $600 service charge.
- SDB Iridium: >700,000 Bpd, 0.149 Ah/d, $221K transmission + $1200 hardware + $600 service charge.

Hardware costs for data telemetry solutions from depth to surface along the mooring line are presented here.

- EOM cable: Unlimited Bpd, no power, $50,000.
- Communication cable: Unlimited Bpd, no power, $1200.
- Inductive modem: 13 MBpd, 0.032 Ah/d, $20,500.
- Acoustic modem: 26 MBpd, 0.096 Ah/d, $47,000.

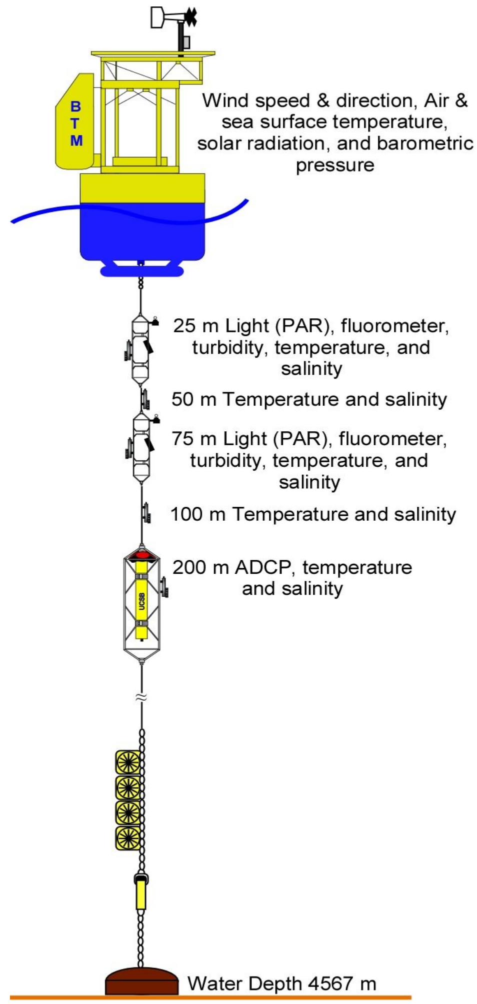


**Figure 2: Schematic diagram of the Bermuda Testbed Mooring - a deep-sea mooring that produces 302,800 Bpd**

## 3. Moorings with Benthic Platforms

Benthic platforms deployed near moorings are included in several design plans of the NSF Ocean Observatories Initiative (OOI) program. One such system includes the coupling of a stationary mooring with surface buoy and a bottom-up, subsurface, autonomous profiling mooring in shallow waters approximately 100 km from shore (Fig. 3). Real-time data transmission can be accomplished via undersea cables that link both platforms and span the distance from sea to shore, or various combinations of methods for transferring data from the profiling mooring to the stationary mooring with surface buoy and satellite, RF, or cell phone telemetry. The two viable methods of linking the moorings include undersea cable or acoustic modems. Once data are transmitted from profiling to stationary mooring, data must be moved up the mooring line to the surface buoy for telemetry to shore. Sensors on the system of proposed moorings in Fig. 3 produce 121,000 Bpd of data (38,000 Bpd for profiler and 83,000 Bpd for stationary mooring). Possible data rates, power usage, and costs of simply linking the profiling to stationary mooring are shown here. [Similar to the BTM, power budgets are computed using SCCOOS power budgets as base values.]

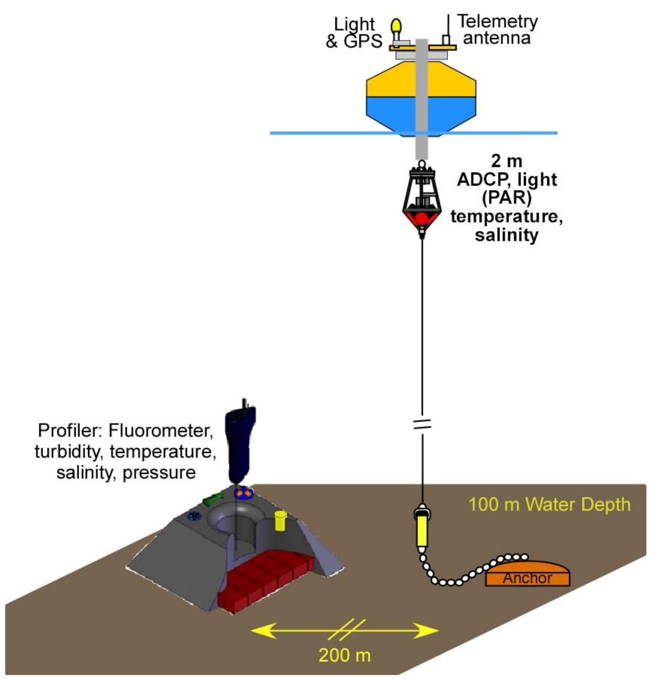


**Figure 3: Conceptual Diagram of an observatory that combines a shallow water mooring with a subsurface autonomous profiling mooring. The total amount of data for the observatory is 121,000 Bpd.**

- Undersea cable: Unlimited data and power, O($300K).
- Acoustic modem: 26 MBpd, 0.012 Ah/d, $18,200.

Techniques of transferring data along the stationary mooring line from depth to the surface buoy follow.

- EOM cable: Unlimited Bpd, no power, $25,000.
- Communication cable: Unlimited Bpd, no power, $500.
- Inductive modem: 13 MBpd, 0.009 Ah/d, $4500.
- Acoustic modem: 26 MBpd, 0.026 Ah/d, $18,200

Data, power, and cost budgets are provided for various real-time telemetry techniques from buoy to shore.

- Undersea cables: Unlimited data and power, O($millions).
- Argos: 256 Bpd per I.D. (needs 473 I.D.s), 0.600 Ah/d for every 4 I.D.s (71 Ah/d), $1.9 million transmission + $1500 hardware for every 4 I.D.s (= $177,375).
- Traditional Iridium: 50 MBpd, 0.089 Ah/d, $1460 transmission + $1200 hardware + $600 service charge.
- SDB Iridium: >700,000 Bpd, 0.059 Ah/d, $88,300 transmission + $1200 hardware + $600 service charge.
- RF (25 repeater stations necessary): Virtually unlimited Bpd, 0.297 Ah/d per station, $1500 x 25 (= $37,500) hardware + $125K for repeater moorings ($5000 each).

## 6. Discussion

As cell phone coverage continues to increase, cellular technology likely will become the best method to transport data from buoy to shore in nearshore environments. Cellular technology provides the highest data rates for the lowest power at the lowest cost (see section 3). Traditional Iridium satellite transmission appears to be the most attractive real-time telemetry option in regions away from cellular service because of its high data rates, low cost, and relatively low power compared to Argos and RF. Undersea cables and Argos technology are, at present too costly to provide reasonable solutions for real-time telemetry.

For data telemetry along a mooring line (for few sensors), communication cables and inductive modems appear to be the best solutions in terms of data rate and power consumption. However, these are generally not robust in most oceanographic applications – mechanical failure is a high probability given even moderate waves and currents. EOM cables may prove to be the best option for systems with multiple sensors if improvements can be made to its ability to withstand ocean movements and costs are reduced. While acoustic modems are the most viable and cost-effective solution for transferring data from a subsurface profiling mooring to a nearby stationary mooring (undersea cables are difficult to deploy), they are too power hungry and costly for most other undersea observatory applications. Research challenges associated with underwater acoustic communications are described in [11-12]. And although the research community is making progress on acoustic modems [13-16] (to name a few), still further advances must be made to reduce acoustic modem power consumption and costs, and to facilitate sensor interfacing.

The data, power, and cost budgets provided here assume transmission of complete data sets collected on an observatory platform. A simple solution to reduce power and costs is to telemeter a subset of the collected data. For example, the SCCOOS current profiler (ADCP) collects data every 12 minutes and the 13 m package records data every hour. Data can be telemetered every two hours and internally recorded during all other periods. Therefore, the 57,000 Bpd data transmission is reduced to 2700 Bpd and transmission costs are reduced accordingly ($1970/yr for SDB Iridium).

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