Wireless architectures for coral reef environmental monitoring

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Abstract. Over the last ten years several wireless architectures have been developed for transmitting meteorological and oceanographic data (in real-time or near real-time) from coral reef ecosystems in Florida, the Caribbean, Saipan, and Australia. These architectures facilitate establishing trends in environmental parameters and aid in ecosystem modeling and ecological forecasting. Here, existing architectures as well as those currently in development are described, incorporating use of Geostationary Operational Environmental Satellites, radio transceivers, wireless digital cellular modems, mobile wireless hotspots, and Android phones. Each architecture is reviewed for advantages and disadvantages, along with some examples of deployments. These summaries provide reef managers and scientists with a suite of options for monitoring, allowing the selection of the most appropriate architecture for the particular needs and capacities of each coral reef location.

Key words: wireless, sensor, coral, reef, monitoring, oceanography, meteorology, in situ, satellite, buoy

Introduction

Sensing the marine environment autonomously has become more essential as civilization encroaches and threatens coral reef ecosystem integrity. Passive data collection, wherein environmental values are stored locally on a sensor, then retrieved days to months later, is only marginally helpful when early management decisions could perhaps keep small environmental or anthropogenic challenges from turning into large or intractable ones. Real or near real-time data reporting can provide environmental managers with an understanding of what constitutes “normal” in the context of their managerial purview. With the proper automated information synthesis from collected data, they can also be apprised of change and act or inform others appropriately. Herein we discuss several wireless architectures for near real-time *in situ* monitoring of the coral reef environment.

Basic Architecture

What we define here as a basic architecture (see Fig. 1) is one that has the following modules: 1) a suite of meteorological and/or oceanographic instruments configured to gather data, 2) an electrical power delivery infrastructure, 3) a data logger for receiving or polling the suite of instruments for data, 4) a radio transceiver for accessing the data logger programming and data, 5) a radio and/or satellite transmitter for sending data away from the station, 6) infrastructure for relaying data received from the remote station to a data archiving center, and, 7) the data and/or information systems home site, including servers and a Web presence for data access. More in-depth discussion can be found in Jankulak et al. (2009).

Advantages. The basic architecture is of necessity for remote sites that are outside existing cellular networks. Projects within NOAA have free access to NOAA Geosynchronous Operational Environmental Satellites (GOES) assigned by region (GOES-East vs. West) and bandwidth requirements. If using a VHF radio or microwave link the cost for data transmittal is free.

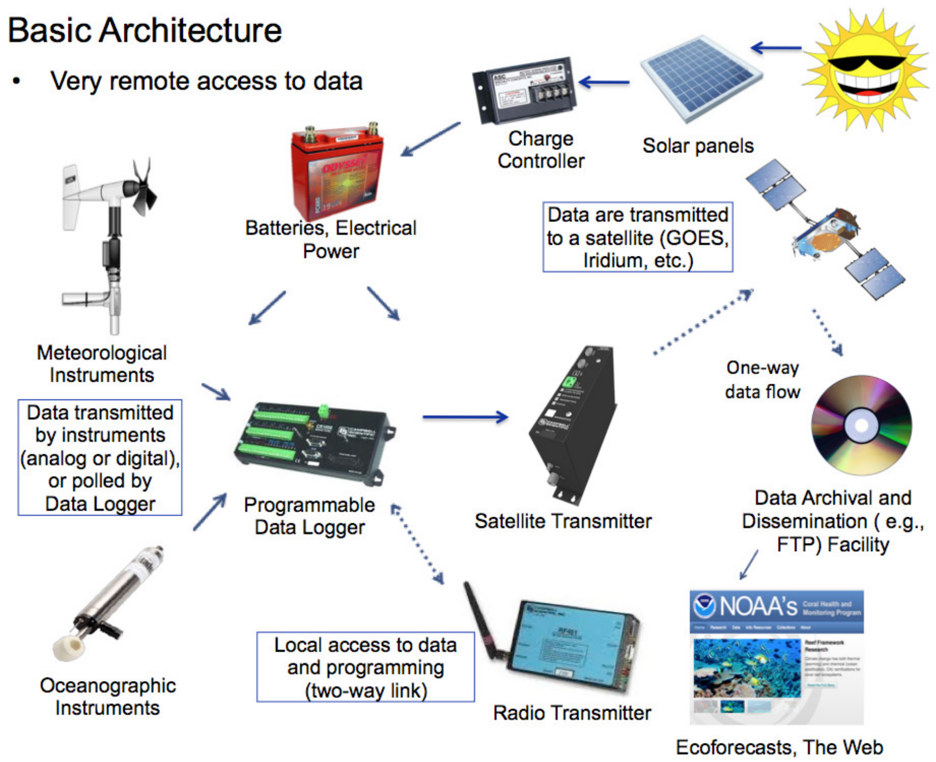

Figure 1: Basic architecture for an autonomous near real-time reef monitoring station (buoy, CREWS pylon, or similar) relying on direct satellite transmission of data.

Disadvantages. The cost of a satellite transmitter can be prohibitive. If a commercial satellite such as Iridium or Argos is utilized, a cost per data message is incurred. Transmission of data during storms is sometimes problematic. Data stream flow is one-way, from station to home base. If this architecture is used on a buoy, contact with the satellite may be prone to outage due to wave action and satellite look angle. Finally, reliance on satellite may impose bandwidth limitations, affecting the variety and time resolution of data that can be transmitted, e.g., large volume: multi-depth ocean current profiles; or high frequency: values every one minute rather than every 60 min. may exceed available satellite channel bandwidth.

Deployment. This architecture has been utilized with various minor differences in the SEAKEYS Network (via GOES; Ogden et al. 1994), the Australian Institute of Marine Science (AIMS) Weather Network (using VHF radio; Berkelmans et al. 2002), and the NOAA Coral Reef Early Warning System (CREWS) Network (via GOES; Hendee et al. 2007).

Wireless Cellular Modem

This architecture (Fig. 2) has some of the same elements as the Basic Architecture; namely, an array of instruments collecting environmental data, and an infrastructure for collecting and distributing electrical power. However, a wireless cellular modem replaces the satellite transmitter, transmitting and receiving data through a local cell phone service provider, for example AT&T in the Atlantic, or DoCoMo in the Pacific. Data received by the provider are then made available through a static Internet Protocol (IP) address, and are thus available over the Internet. A server residing at the receiving host laboratory (e.g., AOML) polls the IP address for the data stream, after which custom software parses it for display of the instrument values on near real-time generated Web pages. The data are also packaged for analysis by an expert system in the generating of ecological forecasts (Hendee et al. 2007).

Advantages. This configuration eliminates the costs associated with utilizing a satellite transmitter and antenna, as well as the cost of data delivery by commercial satellites such as Iridium. This system also has the advantage of two-way communication, so that remote programming changes can be done

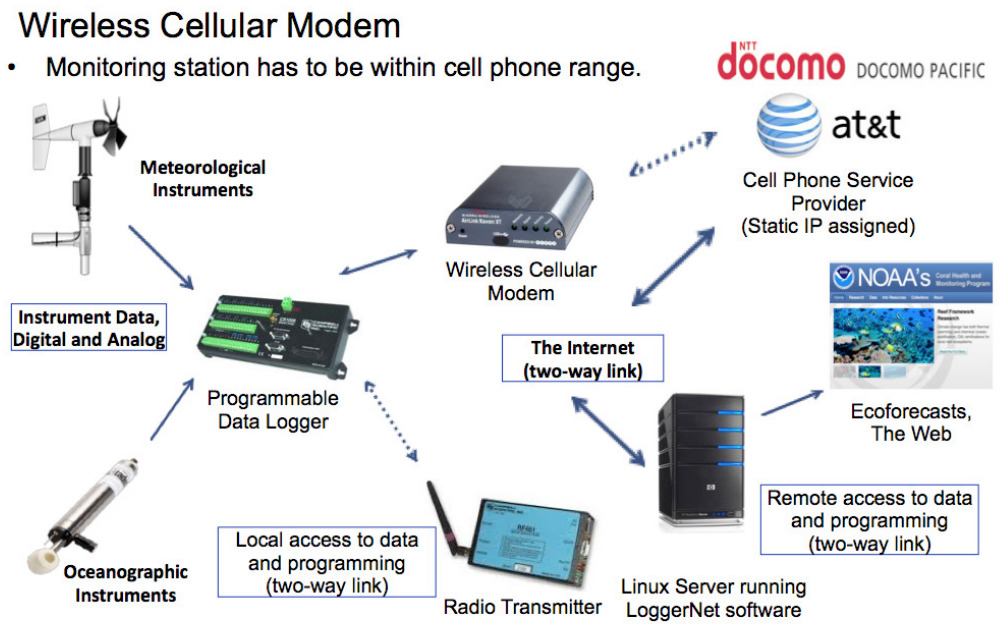

Figure 2: Communications infrastructure for the Wireless Cellular Modem Achitecture, as currently deployed in Saipan and Florida. (Power infrastructure is identical to that shown in Fig. 1.)

from the server site. It is not subject to the bandwidth limitations of satellite transmission.

Disadvantages. This architecture cannot of course be used in areas that are out of cell phone range. There is a monthly charge for cell phone service, so that cost must be weighed against the cost of utilizing other methods.

Deployment. This system has recently (2011) been employed on CREWS monitoring stations near Port Everglades in Florida, and in Lao Lao Bay, Saipan.

Android Cell Phone Architectures

Android is a Linux-based operating system for mobile devices such as "smartphones" and tablet computers. It is developed by the Open Handset Alliance led by Google, Inc. The use of Android cell phones greatly simplifies the acquisition of data from cable, Wi-Fi, or Bluetooth hardware. The Android operating system is an open platform that is highly configurable, providing a high level of flexibility to wireless network applications.

SeaDroid

The SeaDroid project was developed after we recognized the potential of powerful, highly programmable smartphones to provide both data logging and remote transmission using the phone's cellular network provider. Under the SeaDroid project, custom software is currently being developed for Android phones to provide real-time measurements of temperature. The vision is for the SeaDroid package to be accessible to a wide range of reef stakeholders at an order-of-magnitude less cost than existing sophisticated buoy/pylon (i.e., Basic Architecture, above) systems.

The SeaDroid prototype (Fig. 3) interfaces between the sensor and an Android phone (Samsung Galaxy SII) using an Arduino Uno electronics board. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software (see www.arduino.cc). This board provides capability to connect multiple analog and/or digital sensors, as well as external power to the sensors, providing significant flexibility to monitor various and multiple environmental variables. While Arduino boards come with custom firmware (known as "Firmata"), our requirements are simpler; viz., writing a small piece of code to respond to poll requests from the Android phone by writing sensor values to the USB. On the phone, all software development is being undertaken using the Python language in the Android Scripting Environment. The SeaDroid prototype will package data as XML files for transmission.

Advantages. A significant advantage of the SeaDroid system is the high level of configurability of both the Android phone and the Arduino board.

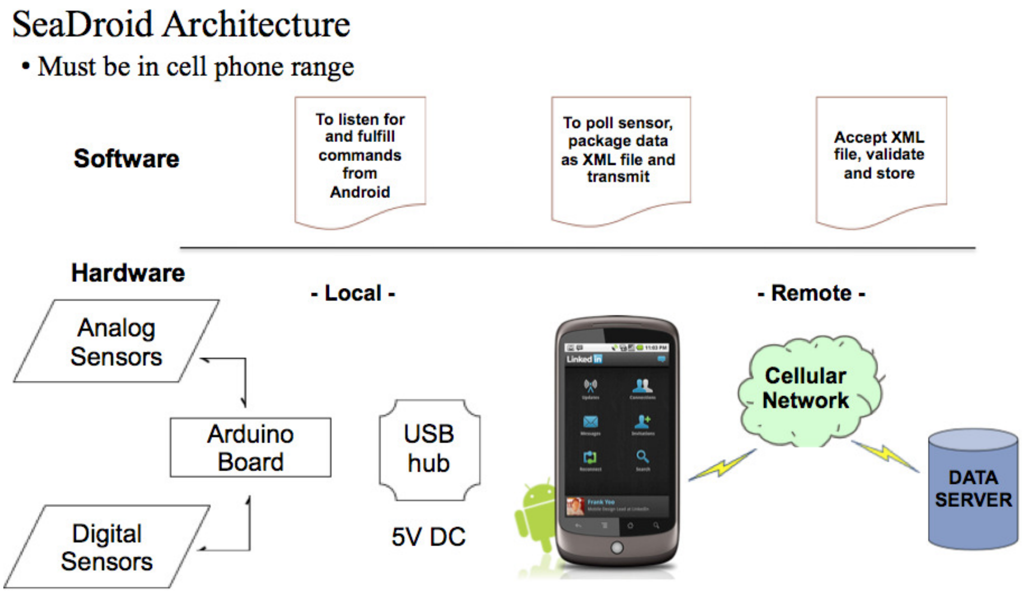

Figure 3: SeaDroid architecture. Multiple analog and/or digital sensors are connected to an Android phone by means of an Arduino board. The phone is programmed to collect data and transmit it through the cellular network to a remote data server.

This means that software can be customized to read multiple sensors for various environmental parameters and package these for transmission to the remote database. The Android handset also provides the ability to: (1) customize the firmware to minimize handset power consumption; and, (2) remotely modify logging parameters during deployment. The flexibility of the Android/Arduino system means that a satellite transmission component could be added. System software can also be developed to choose the best available option for transmitting the data, which would ensure monitoring during network failures as well as provide for moving sensors (e.g., drifters).

Disadvantages. This system relies upon the cellular network to transmit, which may limit deployment locations; it also incurs a monthly cell phone usage charge by the cell phone service provider.

Deployment. This system is currently being configured for deployment on a pole in shallow water along the Great Barrier Reef and eventually for the Florida Keys National Marine Sanctuary.

<u>Other Android Cell Configurations</u>

At least three other methods can be used for connecting Android phones to instruments. 1) Under Android 3.1, utilize the Universal Serial Bus (USB) in host mode to connect to RS232 via converters, then to the instruments. 2) Sensors connected via an RS232 cable to a Wi-Fi transmitter can connect in turn via 802.11b/g wireless mode (up to 125 m) to the phone. 3) A sensor connected via an RS232 cable to a Bluetooth transmitter can also connect to the phone at a range of up to 125m. Bluetooth is more flexible than Wi-Fi communication.

Advantages. The instruments that connect with Android phones can be remotely controlled by free android applications such as TeamViewer and GetBlue. The collected data from the instruments are also saved into online spreadsheet (Google Documents) for real-time monitoring, as well as on a file on an installed SD memory card (up to 32 GB) for data logging on-site.

Disadvantages. Same as for SeaDroid.

Deployment. Currently under development.

Mobile Wireless Hotspot for Local Network

This architecture (Fig. 4) provides a means of serving as the central node for data transmission from a number of platforms in a local networked area. Wi-Fi wireless transmitters connected to a sensor through RS232 cabling can transmit data using an 802.11b/g protocol to a central mobile wireless hotspot (such as that made by AT&T) up to 150 m. Or, the Wi-Fi transmitter can have RS232 to RS485 connectors, with RS485 cabling

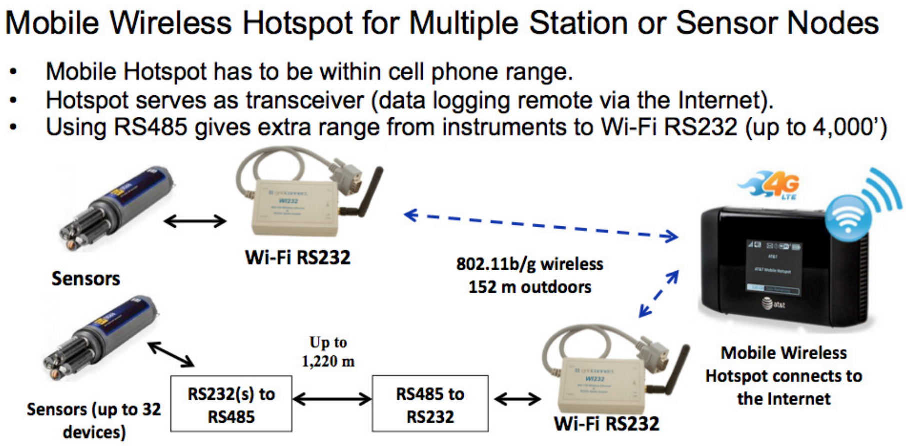

Figure 4: Mobile Wireless Hotspot architecture. Sensors connect to Wi-Fi transmitters that propagate data across a Local Area Network. The Wireless Hotspot (base station) connects to the internet through the cellular network.

for up to 32 sensors and the Wi-Fi transmitter, and can be as remote as 1200 m away.

Advantages. This configuration allows for a large number of sensors, limited only by the system bandwidth. Inclusion of additional sensor-transmitter deployments is seamless as they communicate via the existing wireless network. Sensor types are limited only by bandwidth and can include high-volume transmissions such as streaming video.

Disadvantages. Sensor-transmitter deployments must be within range of the base station or network relay poles, and the base station must be within cellular network range. While expandable, the configuration can become expensive if using many instrumental arrays. System components in the marine environment must be protected but still transmit data.

Deployment. Within the Australian Integrated Marine Observing System (IMOS), an 802.11 wireless network is maintained at the southern end of Lizard Island on the Great Barrier Reef. A series of network relay poles were installed at approximately 1km spacing defining the coverage area. Individual sensors can be easily added into the network across which data are transmitted to the base station on Lizard Island. The authors are unaware of any other maritime use of this configuration, but in theory it is possible, and would be desirable for robust monitoring of an area requiring spatially intensive *in situ* monitoring (e.g., over an extended reef flat or lagoon, or across a reef crest experiencing high spatial gradients of sea temperature).

Discussion

The various wireless configurations described here provide reef stakeholders with the capacity to select the most applicable for their particular location, monitoring requirement and budget. As is implied by the descriptions of nascent technologies, the development of wireless architectures continues to progress rapidly. This will inherently increase the options available for monitoring of coral reefs.

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References

Berkelmans R, Hendee JC, Marshall PA, Ridd PV, Orpin AR, Irvine D (2002) Automatic weather stations: Tools for managing and monitoring potential impacts to coral reefs. Marine Technology Society Journal 36:29-38

Hendee JC, Gramer L, Kleypas JA, Manzello D, Jankulak M, Langdon C (2007) The integrated coral observing network: Sensor solutions for sensitive sites. In: Palaniswami M, Marusic M, Law YW (eds) Proc 3rd Int Conf Intelligent Sensors, Sensor Networks and Information Processing. IEEE, Melbourne, Australia 669-673

Jankulak M, Hendee J, Shoemaker M (2009) The instrumental architecture of a Coral Reef Early Warning System (CREWS) station. In: Dodge R (ed) Proc 11th Int Coral Reef Sym, Ft. Lauderdale, FL 544-548

Ogden JC, Porter JW, Smith NP, Szmant AM, Jaap WC, Forcucci D (1994) A long-term interdisciplinary study of the Florida Keys seascape. Bull Mar Sci 54:1059-1071