Infrastructure for a Sensor Network on Davies Reef, Great Barrier Reef

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Abstract

This paper describes the design and installation of infrastructure to support a sensor network on Davies Reef in the Great Barrier Reef. This infrastructure incorporates a sensor gateway that provides an aggregation point for sensor data, a hybrid power supply and a high-speed microwave link. The resulting system is self-sufficient. It provides a robust interface for a planned sensor network in a location that has limited access and is in an extremely harsh environment.

1. Introduction

The Great Barrier Reef in Northern Australia is a vast ecosystem covering around 280,000km^2 and comprising over 3200 coral reefs [1]. This system is of immense value to Australia in both economic and ecological terms. Despite this importance, monitoring of the dynamics of the Great Barrier Reef has been limited. The Australian Institute of Marine Sciences (AIMS) Sea Temperature Data System (http://www.aims.gov.au/pages/facilities/adc/seatemps.html) is an example of the current approach to monitoring this dynamic environment. Over 160 data loggers recording sea temperatures have been placed at 80 locations on the GBR. They record data at half hourly intervals and are retrieved for download at approximately six to twelve month intervals. There are several problems with this approach including having to wait up to 12 months to get the data, or to discover a sensor has failed or been lost. The need to attend the site to collect the data, restricted temporal sampling to half hourly intervals for power/data efficiency and limited spatial distribution at the reef scale are other problems.

Many of the limitations of this approach can be addressed by the emerging technology of Sensor Networks. These networks provide the ability to gather data at greater temporal and spatial extent than previously possible [2-6]. Furthermore, data can be collected in real time, which has significant implications for research and management.

If sensor networks provide an interface for the cyber world to the physical world, we need to make sure that they are connected. This connection needs to have a high level of availability and have high bandwidth to support a range of sensor technologies including video monitoring. Fulfilling these requirements is straight forward in an urban environment with access to power and data infrastructure. However, the majority of the natural world, by definition, does not have access to these resources.

Figure 1. Location of Davies Reef relative to AIMS and Townsville

This paper reports on the challenges faced in the early stages of the deployment of infrastructure for a sensor network on Davies Reef, 100km northeast of Townsville (fig. 1) This infrastructure includes a sensor gateway, microwave data link and a stand-alone hybrid power supply.

2. ReefGrid, IMOS and GBROOS

ReefGrid is a joint project between AIMS and JCU with funding from the Queensland Cyber Infrastructure Foundation (http://www.qcif.edu.au). It was originally proposed as a trial for sensor networks on the Great Barrier Reef that could be expanded into a more comprehensive system. The first step was to provide the infrastructure for a sensor network on Davies Reef, 100km northeast of Townsville, Queensland. While this project was progressing, the Intergrated Marine Observing System (http://www.imos.org.au an NCRIS http://www.ncris.dest.gov.au/ funded project) has gone from inception to launch. IMOS has been developed to provide a coordinated system of gathering data to support marine climate research in Australia. The Great Barrier Reef Ocean Observing System (GBROOS) is one of the IMOS nodes. GBROOS focus is on providing an observation network for ecosystems of the continental shelf and Great Barrier Reef in northeast Queensland. GBROOS will include the Facility for Automated Intelligent Monitoring of Marine Systems (FAIMMS). The FAIMMS "will deploy sensor networks on locations on the Great Barrier Reef (GBR) to collect real-time data at spatial and temporal scales required to understand complex marine processes". FAIMMS extends on the original ReefGrid proposal and incorporates it within the IMOS.

The NCRIS programs are infrastructure projects and as such, are meant to support research rather than be research. As such the original ReefGrid project supplies research and development support to the FAIMMS.

3. Davies Reef

A. Davies Reef

Davies Reef is located approximately 100km north east of Townsville, and 78km north east of AIMS Cape Ferguson (fig. 1). It is a mid-shelf reef, approximately 7km by 3km in size. This reef was chosen primarily to utilise the existing AIMS weather station tower and for its close proximity to Townsville. Davies Reef is also far enough off shore to be more strongly influenced by ocean than coastal processes.

B. AIMS Weather Station

AIMS have operated a remote weather station (http://www.aims.gov.au/pages/facilities/weather-stations/weather-index.html) on Davies Reef since the 1991. The original tower was replaced with a new structure in 2005. This system collects wind speed and direction, air temperature, barometric pressure, photosynthetically active radiation weather and water temperature. The data is transmitted to shore on a half hourly basis using a 300b/s HF radio link. The structure installed in 2005 provides an excellent platform for the infrastructure required to support a sensor network hub (fig.2).

4. System Design

Data collected from remote sensor networks needs to be aggregated at a point that has high bandwidth access to mainstream storage and processing infrastructure. This aggregation point needs a power source that has a high level of uptime regardless of the conditions.

A. Sensor Gateway

The sensor gateway is an iEi Epic Nano-7240-RS single board computer with 256MB of RAM and an 6GB Micro Drive. This computer uses around 15 Watts under full load and requires a single 12 volt power supply. This low power consumption is the primary reason for its use.

The gateway is using a prototype of SAL [7] to allow a range of sensor technologies to be connected. This device is running a cut down version of Fedora Core 4. Data from connected sensors is collected at various sampling rates, processed and cached locally. The gateway checks periodically for network connectivity, and pushes the data out of its cache to a database server if possible. This ensures unreliable network links will only create a delay but not data loss. In addition, the gateway provides an efficient way to monitor and control the

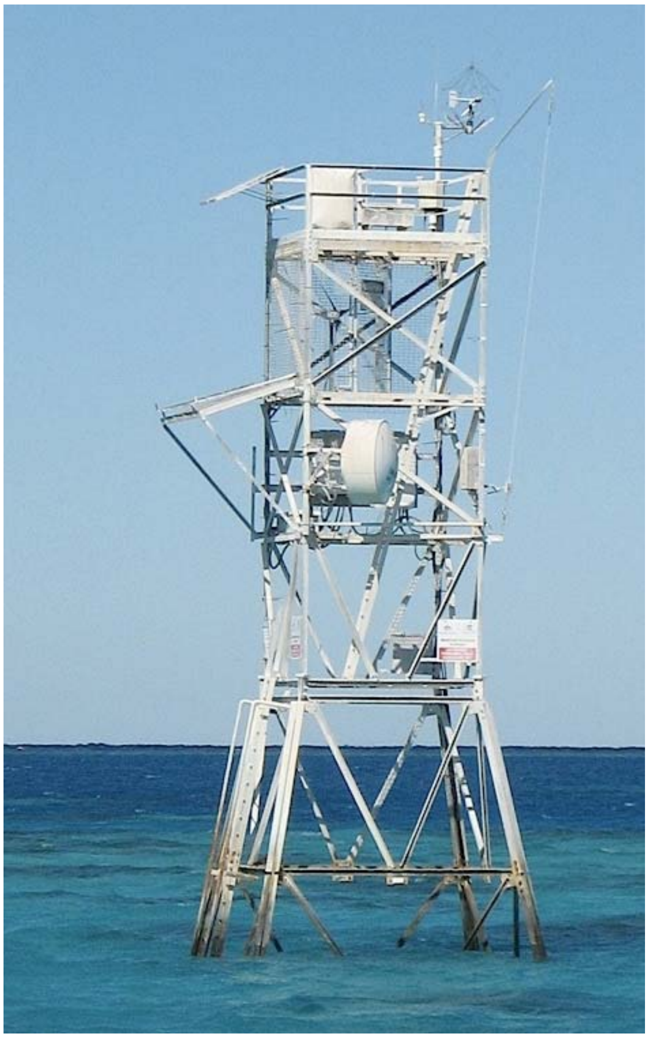

Figure 2. The weather station at Davies Reef. The microwave dish is in the centre of the image. The solar panels for the power system are on the left, the wind turbine is in a bird proof cage on the third floor. Enclosures housing system electronics are obscured by the microwave dish.

state of sensors and power equipment. Intelligent automated decisions, such as shutting down specific devices, can be taken by the gateway when available power becomes scarce for instance. Lastly, the gateway performs real time video encoding and streaming from inexpensive webcams.

B. Microwave Link

The GBR sensor network concept requires a high capacity link from the reef to the mainland. The small volumes of data acquired from temperature sensors and the like would not require high bandwidths. However, if real time video footage were to be collected as planned, a high-speed link becomes essential. Satellite transmission of information is possible, but is very expensive for the transmission of information continuously and at fast data rates. Therefore the requirement to achieve high levels of real-time performance required a novel method of transmission from the GBR to the mainland.

High data capacity radio systems are commercially available and are used in a variety of applications, from linking MANs (Metro Area Networks) to providing building-to-building high speed connections. However, using conventional systems for distances of anything over a few kilometres, normally requires an elevated site at each end, high enough to overcome the curvature of the earth. For the distances being considered in this application (80km), a tower more than 100m high would normally be required. This is obviously not practical on the GBR for environmental, aesthetic and maintenance reasons.

A new method for long-range signal propagation was implemented in this application. Above the surface of the ocean, the rapidly changing humidity from the ocean's surface often forms an evaporation "duct". Radio signals transmitted from within the duct tend to become trapped in this layer and propagate well beyond the optical horizon [8]. Work has been conducted at James Cook University to empirically determine the effects of this phenomenon in tropical regions and compare it to common radio propagation models [9]. Modelling has shown the potential of using this medium for long distance communications with low elevation antennas [10]. The optimum antenna height was found to be approximately 4 meters above the ocean for a frequency of 10.5GHz. There has also been work to determine the expected availability of the duct for a specified link range [11]. It was concluded that an availability of better than 90% should be possible for local conditions.

This work showed the potential of implementing high-speed communications over the ocean for the distances required and at the elevation height available at Davies Reef. Based on these results, an off-the-shelf microwave link operating at a frequency of 10.6GHz was purchased from emSolutions (http://www.emsolutions.com.au). This link had a data capacity of 10Mbps, and a receive threshold of about -85dBm for a bit error rate (BER) of 1x10-6. This bandwidth is sufficient to transport all the information from the base node back to the mainland in real time, at least in the prototype system being developed here. Although not an ideal fit for the project, this equipment was selected due to its ready availability, operation within the frequency band of interest, the high transmission rate possible and emSolution's willingness to assist with the commissioning of the system.

Standard radio equipment like that used in this system is designed for traditional wireless communications deployment, and as such the hardware casings were standard 19U rack width for internal installations. This equipment also relies on convective cooling, as standard indoor installations are in air-conditioned environments. To use this equipment for this application, special consideration needed to be given to the housing the electronics. The major problem to be addressed was that the operating temperature of the unit needed to be kept under 50 degrees Celsius. At the Davies Reef node, the layout of equipment in the housing was arranged so components that dissipated the most heat were spaced well apart. Two 12V, 8.5cm 130mA DC cooling fans were also installed on a dividing wall to force circulation of air in the waterproof housing. A temperature sensor was also installed in the housing to monitor the temperature inside the enclosure. Shade to the base node from the sun on the tower platform was also employed, to help lower the overall ambient heat.

The experimental results obtained from this equipment are expected to help correlate predicted model results, and contribute to determining the characteristics that affect the ability to use the duct as a communications medium.

C. Power Supply

A standalone power supply is required to run the system installed at Davies Reef. The power requirements for the system installed are shown in table 1.

TABLE 1: POWER REQUIREMENTS

Item	**Rated Power (Watts)**
Microwave Modem	65
12V-48V DC/DC Converter	12
5 port Network Switch	6
Sensor Gateway Computer	15
USB Camera, attached sensors	5
12V Regulator	5
Cooling Fans	12
Relay Board	10
Total	**130**

Over a 24 hour period, this equates to a power consumption of 3.12kWh/day. This is the worst-case scenario based on the manufacturers' equipment ratings. Bench testing of the system showed that the power requirements appear to be closer to 80 Watts (~2kWh/day).

A hybrid wind/solar power system with battery storage was designed to deal with these power requirements. The design of this power system was done with the assistance of HOMER [12], a modelling package that allows the evaluation of design options of hybrid power systems. HOMER was used to evaluate different system designs. HOMER allowed energy resource information such as wind and solar data to be incorporated into the design. AIMS provided wind data recorded every half hour for Davies Reef from 1998 to 2003. HOMER can take wind data either as monthly averages or as hourly averages. The AIMS wind data was resampled to get hourly data to input into HOMER. The annual average wind velocity varied between 6.91ms^{-1} (2001) and 7.63ms^{-1} (1999) for the six-year period covered by this data.

Daily Solar Radiation data as monthly averages were obtained from NASA's Surface meteorology and Surface Energy website [13]. HOMER calculates hourly data based on these monthly averages. The NASA website also has daily averages for each year from 1983 to 1993. The annual daily average for this period ranged from 5.90 kWh/m^2/day to 6.23 kWh/m^2/day.

To test various system designs, the worst-case load scenario of 130 Watts continuous power consumption was assumed. The year 2003 wind data was used (average of 7.12ms^{-1}) with sensitivity analysis carried out over a range from 6.5 ms^{-1} to 7.5 ms^{-1} (HOMER scales the data for these sensitivity analyses, maintaining the overall distribution). The monthly average solar data was used with a sensitivity analysis range from 5.9 kWh/m^2/day to 6.07 kWh/m^2/day.

Power components considered were one or two Southwest Windpower AirX Marine wind turbines, up to four 125 Watt solar panels, and up to 600Ah of battery capacity. Sensitivity of the system to a loss of efficiency of the solar panels as a result of fouling by bird droppings or salt build up was also checked, with efficiencies of 60%, 75% and 90% considered. Scenarios with 0%, 1%, 2% and 5% capacity shortage were analyzed.

In the worst-case scenario, with maximum load, minimum wind and solar power (radiation and efficiency), the optimum system has four solar panels, two AirX turbines, and 600 Ah of battery capacity. This system still has 2% (~7days) of unmet demand. When the system is run with the microwave at 50% duty cycle, 100% availability can be achieved with three solar panels, two AirX turbines and 600Ah of battery capacity. Increasing the efficiency of the solar panels to 75% makes a four solar panel, single AirX turbine and 400Ah of battery capacity system the most favourable still with 2% unmet demand at maximum load and 100% availability with the microwave at 50% of its duty cycle. The sensitivity analysis showed that the optimum system has either three solar panels and two wind turbines or four solar panels and one wind turbine, depending on solar panel efficiency, total solar radiation, and average wind speed.

Taking into account ease installation and maintenance issues, the system installed used four 125 Watt solar panels, a single AirX Marine wind turbine and six 100Ah batteries. This system provided the best compromise for available power, ease of installation and future maintenance.

A Solar Power Regulator is required to regulate the output of the solar panels to provide optimum charging characteristics for the batteries. A Plasmatronics PL40 unit was used. The charge cycle of this device can be fully programmed and it allowed the output of the solar panels and wind turbine to be monitored as well as keeping track of the condition of the battery bank. The AirX Marine wind turbine has its own inbuilt regulator. It operates only within the boost stage of the battery charging cycle, cutting out when the battery voltage reaches 13.8 Volts. The turbines output is monitored using the Solar Power Regulator.

5. DEPLOYMENT

Two key issues were faced during the deployment of the system. The first was the difficulty in deploying a system in such a remote location. The fact Davies Reef is a 50 nautical mile boat trip from Townsville combined with bad weather and staff availability problems meant that thorough preparation was essential. The approach taken with the design of the system, using tools like HOMER to simulate the power supply, reduced the chances of complications with the installation. Bench testing of the system was also valuable in highlighting potential issues prior to deployment.

The second issue was the extent of the bird problem. Birds were always expected to cause problems by fouling the solar panels. They are also damaged the blades of the wind turbine forcing us to move it into a bird proof cage. A frame has been placed over the solar panels to stop birds from roosting on them. This appears to have decreased the amount of fouling, although it has not stopped the problem altogether. The panels are cleaned by rain events; however, these are infrequent from May to November. We are investigating other means to reduce this problem further.

6. PERFORMANCE

The system has been operational continuously since 20 July 2007. The power supply has been able to supply power without interruption during this time. A continuous set of data has been collected, at 20-second intervals, from the limited array of sensors deployed during this time. While the microwave link is active, a video stream is also available.

The microwave link has had an availability of 80% during the first two months of operation. The 20% downtime is a result of weather conditions unfavourable to the establishment of a humidity duct. Preliminary analysis suggest that low wind velocities and cold south to westerly winds (blowing off the land mass towards the sea) produce such conditions.

7. WHAT NEXT

The infrastructure is now in place to allow the deployment of a sensor network at Davies Reef on the GBR to commence. Initially, this will comprise wireless sensors with thermistor strings connected to buoys. There will be challenges in developing appropriate housings for these sensors, dealing with fouling and in propagation of radio signals close to the ocean surface. Two IP cameras will also be deployed, one on the weather station and one underwater.

This facility will also provide a long-term dataset for the development of better propagation models for microwaves in the tropical humidity duct. Now that this communication method has been proven, development of optimised radio communication equipment and modulation techniques for this application will be pursued. Ways to store and forward data to suit the availability characteristics of the link will also be pursued.

8. CONCLUSIONS

The challenges of deploying the infrastructure for an environmental sensor network in a remote, marine environment have been discussed. The key components are a sensor gateway (providing a data aggregation and sensor access point), a novel microwave data link and a standalone power supply. This integrated system is a significant achievement in providing a link to the natural world. This is the first time that a microwave data link has been established on a permanent basis using the tropical humidity duct anywhere in the world.

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