Real World Issues in Deploying a Wireless Sensor Network for Oceanography

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ABSTRACT

In this paper we describe some of the practical issues involved in designing, building and deploying a sensor network for oceanographic monitoring. The paper explains some of the design decisions and their consequences, and some of the lessons learned from a first sensor network trial at sea.

Categories and Subject Descriptors

C.3 [**Special-Purpose and Application-Based systems**]: - *microprocessor/microcomputer applications.*

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design - *wireless communication*.

General Terms

Design, Experimentation, Algorithms

Keywords

Wireless sensor networks, environmental monitoring, design, deployment

1. INTRODUCTION

Oceanography is the study of processes that govern the complex interplay of tides, currents, waves, and seabed and coastal modelling. Oceanography can tell us about coastal deposition and erosion and consequently about flooding and sea defences. An area of particular interest for this work has been Scroby Sands, a sandbank off the coast of Great Yarmouth where a windfarm has recently been constructed. The sandbank is interesting oceanographically, providing a sheltered coastal region, but also a raised feature in the seabed which exhibits a highly dynamic topography[4]. Scroby Sands therefore offers the opportunity to study not only active sedimentation and wave processes in the area, but also how this may be affected by the building of the windfarm, which consists of 30 large (100m tower height) turbines.

Sensor networks offer a new paradigm for oceanography, and many other scientific, commercial, agricultural and industrial applications. Deployments of sensor networks for environmental monitoring include work on Duck Island, Maine[7] and work in Western Australia on water balance[1]. Our aim was to enable oceanographers, represented by UEA in our consortium, to collect spatially distributed data points, by providing a spatially dispersed measurement array that was at least one order of magnitude cheaper than conventional oceanographic kit. This should enable a much richer characterisation of complex oceanographic processes, especially near-shore, where large-scale macro models do not hold.

As well as exploiting cheap sensors, the sensor network has been designed to operate autonomously, and adapt its rate of taking measurements, data processing and network communication, to local conditions that are not known a priori.

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Power management has also been central to the design, with the autonomous AI used to control sensor node operation on the basis of available resources, in particular: communication bandwidth and battery power[5].

Prior to prototype development, device intelligence and networking techniques were devised and simulated and have generated novel and exciting new approaches[2,5]. However, the main subject of this paper is the more practical issues involved in going from the ideas phase to prototype deployment. This work was carried out in the SECOAS project, which was part-funded by the Department of Trade and Industry, as part of their Next Wave Technologies and Markets initiative, and involved collaborative work amongst BT, Intelisys, University College London, Kent University, Essex University and the University of East Anglia.

2. PROTOTYPE DESIGN

The sensor package was designed as a waterproof cylinder (approx 50cm long) containing a sensor section, a data-logger and a microprocessor (PIC) running the lightweight device control algorithm, designed to control the measurement rates, data processing, queue management, data aggregation and data forwarding, together with 2 alkaline D-cells. The sensor package is designed to last several months using these batteries. Attached to this cylinder is a 'dongle' which is able to move in the current, and thus provide current velocities. The sensor section incorporates a temperature sensor, a water-pressure sensor, from which wave-height can be derived, an optical backscatter sensor that measures turbidity, and an electrical conductivity sensor, which is used as a surrogate for salinity. The sensor package is suspended within a pyramidal-shaped cage, designed to remain fixed on the seabed, thereby giving a consistent reference orientation for current velocities and clearance above the sea bed for the optical sensor.

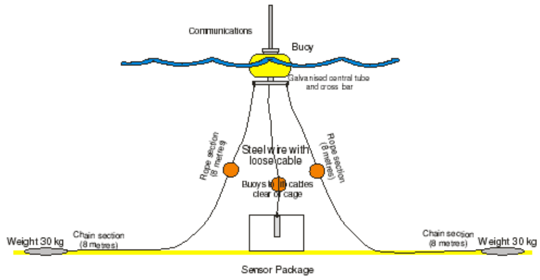

Figure 1. Sensor node mechanical design.

As part of prototype design, a decision was taken to modify a mooring buoy, to house the radio and antenna, rather than having a bespoke buoyancy housing made. This was a good decision in terms of cost, but also had the advantage that we could get advice on appropriate moorings for the buoy, and the buoy was bright yellow, meaning that it was an approved colour that would be visible and recognised by sea-going traffic. Metalworking was needed to give a platform on to which a waterproof box could be attached, to house the radio electronics and batteries. We were also required by marine authorities to put a light on top of the buoy. The total cost of manufacture of one node, including sensor package, cage, cables, ropes, chains, radio buoy, machining, electronics housing, radio, batteries and light was approximately one thousand pounds. This is an upper limit for this node design, representing small-scale manufacture, without the efficiencies that can be achieved with scale. Already this is easily one order of magnitude cheaper than typical oceanographic kit, with the prospect of another order of magnitude (down to a few hundred pounds) for large-scale manufacture. These cost advantages are also supported by technological advantages of adaptive sampling, robustness through node redundancy, and autonomous operation and data collection, plus the fact that our devices can measure current velocity (speed and direction) which is not typically available to oceanographers using conventional equipment.

The radio frequency was selected from the range of unlicensed ISM frequency bands. The propagation characteristics of a number of frequencies were investigated at sea and of those 173.25 MHz was found to offer a good compromise between antenna size, and range. Results indicated that using +10dBm RF power, a theoretical link length of 1.5 km at a data rate of 10 kbps was possible in calm conditions, using sea level antennae. Higher rates were possible for shorter distances. Key to our approach has been the ability to increase the rate of measurements, in order to gain greater resolution of phenomena when these are of greatest interest, i.e. changing rapidly and unpredictably. At these times, the bandwidth is not sufficient to send all these measurements immediately. However, the node management algorithms enable data storage and data processing, in order that the most 'interesting' measurements take priority, in terms of available bandwidth [5]. Wanting to keep the profile of the node small, and in particular the torque on the buoy, during windy conditions, a half-wave monopole antenna was chosen for a frequency of 173.25 MHz, that being around 50 cm in length.

3. PRETRIALS

3.1 Mechanical Trial

The first sea trial off Great Yarmouth consisted of a week-long deployment of a sensor package and cage with software running, attached by chain to a buoy. This was essentially a mechanical trial, to verify the efficacy of the moorings, and to check that the box on the buoy, designed to house the radio, was waterproof. A significant part of the experiment also concerned physically deploying the system and recovering it. We used two weights to moor the buoy. The idea was that opposing moorings would prevent the buoy from twisting, which would be important to prevent twisting of the cable to the sensor package. The line to the cable package was designed to remain slack, with the mooring ropes under tension. Attached between the mooring ropes and mooring weights was heavy chain, designed to lie on the seabed, and prevent the weights from being dragged. We were aware that if the weights once lifted, the whole equipment would most likely be carried out to sea. Our week-long trial with sensor package at about 8m depth showed that the moorings were stable, at least for these moderate sea conditions. We were able to recover sensor data and verify that the node intelligence algorithms were stable and reliable[5].

Figure 2. Photo of deployed radio buoy.

At the start of the mechanical trial, we held a public meeting with local fishing groups, and informed them of the location of our deployed buoy, which had been positioned outside the shipping lanes and away from known fishing areas. This meeting was part of our application to the Marine Consents and Environment Unit (MCEU), to be allowed to carry out sensor network trials at sea in this area. Ultimately we were granted a licence by the MCEU to carry out our two network trial deployments, the first, which is the main subject of this paper, to be carried out with 6 nodes, for one week, in October 2004. A radio licence was also applied for and granted by OFCOM to enable radio experimentation at 173.25 MHz, within specified power limits and in the deployment zone. A licence was also purchased from Crown Estate to allow equipment to be placed on the coastal seabed.

3.2 Radio Trial

The second mini-trial was essentially to test the range and visibility of the radio buoy antennas, in open sea. We stationed ourselves on the shore, in a caravan park, just above the dunes (5-8m above sea level). A prototype radio buoy was constructed, taken out in a boat, and set to transmit diagnostic packets from a number of points at various ranges from the shore. Positions were logged from the boat with GPS. With a YAGI antenna in our hands, attached to a receiver radio and laptop, we listened to the diagnostic packets being sent from the radio buoy at sea, and were able to assess the radio visibility of the buoy. In spite of the small size of the antenna (0.5 m), in relation to typical wave heights that can reach several metres in storm conditions, good signal strength was received, in light to moderate sea conditions, with acceptable bit error rates, for ranges of up to 3km.

4. FIRST NETWORK TRIAL

4.1 Integration

The first system trial took place over 2 weeks in Oct 2004. This trial was the first time the sensor package had been linked to the radio buoy in field conditions. The sensor controller acted as the master, polling the radio and sending data to the buoy when the radio controller indicated availability in response. This data transfer took place over a 12m cable linking the seabed package with the radio buoy via RS232 ports.

4.2 Networking

The longer term intention of the work is to create a large scale network incorporating hop-hop communications, and exploiting self-organizing clustering. However, for the first network trial it was decided to experiment with a simple single cluster as a representative of one element of the target system. This experiment was designed particularly to produce an accurate characterization of network settings for the oceanic environment. The focus was on single hop link behaviour as the appropriate first step in understanding the challenges that sea conditions create for networking. A 'star' type of network was deployed, with a cluster-head. See Figure 3. The experiment created the data to enable parameters of sea-to-sea and sea-to-shore packet exchange to be deduced, over time and at different sea states. Tools, instruments and programs were deployed to record received signal strength information, bit error rates, synchronisation parameters and specific ARNEO (Autonomous Resilient Network for Resilient Environmental Observation) parameters, such as induction sequencing and persistence[3].

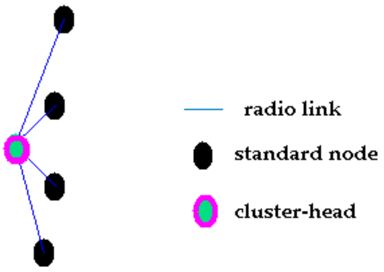

Figure 3. Network topology.

4.3 Node Assembly

We chose a venue for assembly in Great Yarmouth, as it made sense to have a short trip to sea for the nodes which, though very lightweight in terms of oceanography, were bulky to handle. The moorings were loaded on to an ex lifeboat vessel, and moorings were attached to each buoy, prior to launch. For water-tightness, the radio box was packed with resin. The radios themselves were first put into plastic bags, with the hope that the resin would not prevent them from being probed and possibly re-used after the trial. All holes and channels through the buoy, through which the data cable passed were also squirted with resin, as was the entrance to the sensor module. Unfortunately, immediately prior to expected launch, some of the sensor modules appeared not to be sending any data along the cable. This led to the sensors being cut off to be fixed. This was caused by a last-minute software change which had had an unexpected fatal side-effect. The software was soon put right, but this resulted in having to attempt a water-tight junction to re-join the cut data cable. Despite our best efforts in filling this junction box with resin, this was inevitably a weak point, and probably caused the failure of one of the sensor modules, due to water leakage, at deployment.

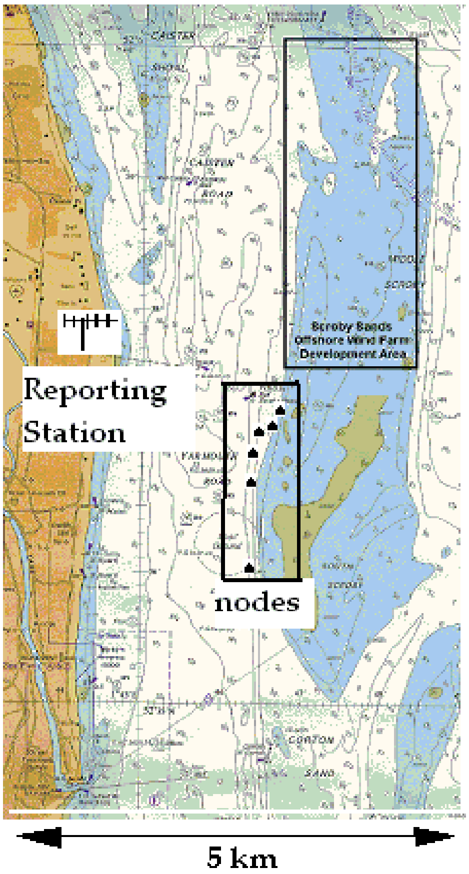

Figure 4. Map[4] showing positions of nodes and report station.

4.4 DEPLOYMENT

Following the mechanical trial, we expected to be able to deploy 6 nodes in one day, weather permitting. Luckily, it was close to flat calm. Deployment was carried out parallel to the direction of the tidal current, and at high tide, when the tidal current is weak, and the sensor modules are at maximum depth. Locations were chosen to be close to the sandbank, in shallow water, immediately south of the windfarm. See Figure 4. Engines were cut to prevent interference of the propellers with the ropes and chains, and the first mooring was dropped overboard. The tidal current caused the boat to drift parallel to the shore. Waiting for the rope to go tight, the sensor module was then dropped overboard, closely followed by the radio buoy, and then – as the second mooring rope began to tension - the second mooring weight was thrown overboard. It was useful to have an additional short loop of rope on the top of the buoy to help to prevent the buoy becoming submerged. Although, where capsize did occur, we found that the buoys righted themselves, and were stable with the antenna out of the water. However, the deployment of the sixth node showed that this stability depended on the strength of current acting on the buoy and mooring system. The first five sensor nodes were deployed at depths of around 6m, where the tidal range would vary this by +- 1m. The sixth buoy, placed the deepest, at around 10-12 m, was also in a more exposed position, in relation to the sandbank, and the current here was much stronger, and tending to pull the buoy under water.

4.5 Reporting Station

A reporting station was set up at a caravan facing the sea front. The reporting station included a radio snooping device, two PCs redundantly logging radio events, and a RSSI logger. The radio snooping device was implemented with a seven element yagi antenna and a radio board running on batteries. The two PCs logged the radio events being produced by specific networking diagnostic software running on the radio snooping device. The RSSI logger sampled the RSSI output PIN available from the radio receiver of the radio snooping device. The detailed reasons for this design will be published subsequently.

4.6 Weather

From an oceanographic point of view, and an experimental point of view, we had ideal weather for the trial. Initially it was flat calm, but, over the next 24 hours, the winds became much stronger, reaching gale force after two or three days. Our concurrent observations from a fishing association said 'S/W gale force overnight and into the morning. Seas moderate to rough. Waves up to 3m high on sand banks. Not suitable for fishing. Clarity of water very poor. Current speed approx 2-2.5 knots.' At this point, small fishing vessels were unable to put to sea, and we were able to gauge the performance of the radio communication and the mechanical design of the nodes in adverse conditions. In spite of strong winds and heavy rain, information derived from the networking diagnostics received up to 3km away on the shore, indicated that network activity was still taking place. Further details will be included in a future paper.

4.7 Node Recovery

Due to the change in the weather, we could not recover the buoys on the expected day, but had to leave them in the sea for about 10 days in total. When we came to look for them, the moorings had held well, even in the faster moving current. Knowing that it had been arduous to lift the mooring weights manually back into the boat, following the first mechanical trial, we had also experimented with anchors instead of weights, for 3 out of the 6 nodes deployed. The anchors did an equally good job, and were marginally easier to pull in. Recovery was certainly harder than deployment, taking more effort and more time. The method of deployment had ensured tight moorings, which therefore offered little flexibility for hooking out the buoys. In the most dramatic buoy recovery, the whole node, including sensor cage and moorings became entangled around one of the boat's propellers and had to be removed in a dry dock. However, all the sensor modules and radio buoys were ultimately recovered intact.

4.8 Results

One of the sensor modules failed almost immediately, on deployment. We suspect that this was because of water ingress along the data cable from a cable junction. Another sensor module exhibited faulty behaviour after a couple of days of deployment, which we can also attribute to water ingress.

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[4] Permission to reproduce chart applied for from UK Hydrographic Office.

However, in general the sensor modules behaved as expected. The independence of sensor and radio modules enabled the radio networking side of the experiment to be unaffected by the sensor module failure.

In all, about one and a half million remote radio/network transactions were recorded, producing a large multivariate log for further analysis. More than 50 million samples of locally collected high resolution RSSI data were recorded. We have started analysing the results, and the viability of the mechanics, node management software, radio and antenna has been demonstrated.

In addition to the data samples transmitted, a comprehensive data set was retrieved from the deployed data loggers. This is being used as an ideal reference with which to test the sampling and aggregation strategies. An example of unprocessed data of water pressure recorded at 3 nodes over a 10 day period is shown in Figure 5, from which the tidal cycles are clearly visible. At finer granularity, wave activity can be observed.

In terms of node intelligence, we found that a rule based approach (sliding window averaging) was successful in reducing the amount of data to be transferred, while minimising the loss of information [5]. This type of systematic approach lacks adaptive behaviour but benefited from local learning feedback that modified probabilities of certain actions based on internal and external conditions [5]. Making these probabilities evolvable and transferable between devices has been shown to increase robustness by optimising parameters in real time [6].

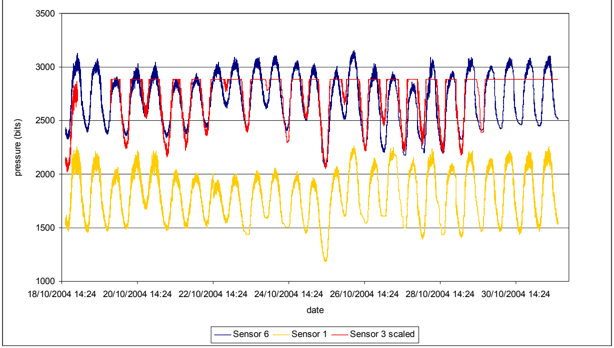

Figure 5. Unprocessed pressure sensor data from 3 nodes.

From a sensor point of view, the pressure sensor calibration was not ideal for the deeper node depth of around 12m, but this is easy to adjust. The turbidity sensor gave occasional aberrant readings, but this was probably due to a piece of weed being introduced into the sensor chamber. Prevention of such large debris entering the chamber is relatively easy. A second longer trial, in autumn 2005, will provide a better characterisation of the oceanography, as well as an improved network functionality.

5. LESSONS LEARNED

Early analysis indicates that sea-to-sea communication can produce tremendous stresses on networking that could lead to its collapse, supporting the need for specific approaches that include properties of autonomy and resilience. (Full results will be published elsewhere.) The experiment was also a good indicator of the suitability of the algorithms for computing resource constrained platforms[3,6]. Improved versions of the radio devices are in the process of being designed and tested at Essex University, which will deliver improved performance, with considerably less power consumption.

The basic node design was reasonable for the conditions to which it was exposed. Even the node at the southern-most point of the sandbank remained moored. We were able to show that the node management software was stable, with analysis of its performance being published elsewhere [6]. However, clearly there was at least one design omission, in not having a manual node re-set. One of the early premises of our work has been reprogrammability of our nodes, remotely, via the network. This feature would also have helped if we had had time to implement it for this trial. It certainly remains an important design goal.

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