Sensor Network Implementation Challenges in The Great Barrier Reef Marine Environment

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Abstract: The Great Barrier Reef (GBR) in Australia consists of 3200 coral reefs extended over 280,000 km^2. Coral reef ecosystems are areas greatly susceptible to impact of global climate change as well as other man-made influences. This creates an urgent demand for the sensor network technologies to be deployed in order to perform essential environmental monitoring and information collection. Analysis of these data can provide predictive information on destructive events such as coral bleaching. This paper analyses sensor network deployment issues in relation to harsh marine environment. Definitions for different kinds of node displacements experienced in the sea are provided, namely first, second and third order displacements. The effect of these displacements on the communication between sensor nodes is also analysed. Further more, we propose to use Microsoft SensorMap to provide a platform to disseminate the information collected from weather stations and sensor networks to the worldwide coral reef research community and also to the worldwide sensor networks research community. Details about publication of data on the SensorMap from the existing Australian Institute of Marine Science (AIMS) weather stations are provided.

Keywords: Great Barrier Reef, Wireless sensor networks, Marine environment, wave dynamics, SensorMap.

1. Introduction

The environmental dynamics of marine systems such as the Great Barrier Reef (GBR) are complex and thus require greater understanding in order to manage anthropogenic stresses effectively [1]. With over 3,200 reefs extended over 280,000 km^2 [2], the scale of the fluctuations range from kilometre oceanic mixing to millimetre inter-skeletal currents. The strategic collection of data at appropriate scales is critical for effective environmental monitoring and analysis [3]. Modelling environmental patterns at this early stage of global climate change awareness leads to high levels of uncertainty [4]. Thus the timely collection of information on this marine environment is essential for the development of robust models. Although existing data logging systems provide valuable information, the high acquisition costs and inability to retrieve the data in real time is leading the marine research communities to examine emerging technologies such as sensor networks for real time acquisition of the data.

The Australian Institute of Marine Science (AIMS) has a number of autonomous weather stations throughout Australia to collect environmental data. This information is automatically quality checked and stored in the data centre before being delivered to web based visualisation tools. Collecting real-time data at appropriate temporal and spatial scales is critical to understanding complex marine processes. The emerging generation of 'smart' sensors presents new opportunities for automated intelligent monitoring of marine systems.

Technical challenges to achieve this revolve around fouling and corrosion of equipment used under water, power requirements and the general problems of maintaining equipment in a remote and hostile environment. There are also a number of sensor network challenges specific to marine environment that needs to be addressed. This includes: the implementation of high-capacity communication links to remote areas; the storage and manipulation of the large volumes of data generated (including video); the integration of the data into modelling and visualisation systems and the ability to manage and maintain a system that is inherently more complex than the simple passive systems deployed currently. In this paper, challenges in deploying sensor networks in the GBR are further analysed. Furthermore, a sensor network specific problem unique to marine environment is maintaining connectivity (and there by successful transmission of data) amongst the nodes despite the node mobility induced by the wave dynamics. This paper analyses these movements of nodes and provides a way to schedule the communication time window for improving successful data transmission over the network.

Microsoft SensorMap provides a map interface for the sensor data. It provides tools for visualisation of sensor locations and query interface for the sensor data [16]. This paper provides details about the web publication of the data collected from existing AIMS autonomous weather stations using the Microsoft SensorMap.

This paper is organised as follows. Section 1: Introduction; Section 2: Analysis of the challenges related to sensor network deployments in the GBR. A specific problem of connectivity of sensor nodes with mobility is analysed in Section 3. Section 4: the SensorMap for the GBR and, section 5 concludes the paper.

2. Sensor Network for the Great Barrier Reef

Wireless sensor network implementation in harsh marine environment such as the Great Barrier Reef (GBR) poses various challenges. Such challenges include design and deployment of reliable mooring systems which can cope with tides, currents and tropical storms. The typical mooring for sensor nodes used to measure marine parameters such as temperature and salinity usually consists of floating buoys, which are fixed to the ocean floor by means of connecting medium such as cables. Below we describe in detail challenges related to deployment of sensor networks in marine environment.

Integration of specialised sensing elements to the sensor nodes: Monitoring marine parameters in the sea are different from monitoring in land. Specialised sensors for marine environment have to be integrated to the sensor nodes such as iMote2 nodes from Crossbow technologies [5] and µ-nodes from Ambient technologies [6] to use them in sea water. Furthermore, for the collected data to be useful for scientific purposes (marine biology and oceanography) the sensors have to be calibrated before deployment using devices with current calibration certificates traceable to recognised standards laboratories (NIST [19], NRC, NPL, etc.).

Buoys and casing for sensor nodes: Sensor nodes have to be deployed using floating buoys with water proof casings to ensure proper functioning of nodes in the water. Buoys are usually fixed to the ocean floor to prevent nodes from moving and disappearing in the sea. Further, experiences form previous sensor network deployments reveal [6, 13] that fouling and corrosion of equipments is an issue to be taken into consideration in deploying sensors.

Mobility of sensor nodes within limits: The buoys will not remain stationery with respect to the initial deployed position due to ocean currents and tides. Hence the sensor nodes will experience radial (vertical), tangential (horizontal) displacements and slanting at any given position due to currents. This poses some unique challenges in maintaining communication amongst the other sensor nodes in the network. This challenge is further analysed in section 3.

Communication scheduling: Sensor nodes in the network need to communicate amongst themselves to transmit measured data via multi-hop or directly to a base station. The data is stored in a data logger which in turn can be collected by regular site visits or by other means of communications such as microwave links as used in Davis reef weather station [7]. The main characteristic of wireless sensor networks is that they are resource constrained, as they usually rely on using compact batteries for power. Most of the power in sensors is consumed in radio communication. For example, in Sensoria sensors and Berkeley motes, the ratio between communication and computation energy consumption ranges from 10^3 to 10^4 [8]. Hence, continuous transfer of data will reduce the life time of the network. Therefore, the communication between nodes needs to be scheduled using sleep and wakeup cycles by means of scheduling algorithms such as L-Mac [9], in order to prolong the life time of the network.

Self storage of data: Sensor nodes need the ability to store limited data on board for later transmission or for further processing. This is very important for marine studies since the data collected during storms, cyclones and other events in the ocean that can result in loss of communication could be very valuable for scientific understanding of these events. Recently Mathur *et. al.* [10] have observed that by using parallel NAND flash technology, large amounts of data storage with low power consumption can be obtained for sensor nodes [10]. This boosts the memory capacity of each sensor node enabling on-board processing in the sensor. This provides robustness of the network for loss of data due to any communication failures during operation in the harsh marine environment. Furthermore, data aggregation (such as averaging) and data conditioning (such as anomaly detection and correction) can be performed on board on the data collected before transmitting to the base station. This helps to reduce the communication overhead in the network and thereby prolonging the life time of the sensor network.

Heterogeneous network: The spatial requirements for marine study area could range from few meters to few kilometres depending on scientific question behind it. This requires scalable network architecture for sensor networks. Networks consisting of homogeneous nodes are not scalable due to its resource limitations. Therefore, heterogeneous sensors with varying resource capabilities such as power, memory and computational capabilities need to be used to build reliable and healthier networks with extended lifetime. Network topologies such as in clustered topology, nodes with different capabilities are arranged in different layers for communication. Figure 1 shows schematic diagram of a planned sensor network deployment by AIMS in Heron Island during latter part of 2008, which consists of heterogeneous nodes to cover the whole island for collecting ocean parameters. Initially the *large buoys* (first tier) fitted with solar panels and the *medium buoys* (second tier) will be deployed in the water (Note that in Figure 3, the light blue area shows the lagoon area). At a later stage sensor nodes (third layer) will be deployed around each medium buoy to collect temperature and salinity data at much finer spatial resolution. These sensor nodes will be smaller, cheaper, powered by small batteries and will communicate with the base station

that is housed in the medium buoys via single or multi-hop. Tenet [11] and SensEye [12] are examples of other sensor network architectures with multi tiered heterogeneous sensors.
Anomaly or event detection: The sensor measurements collected by such sensor network deployments can become contaminated with errors (either fully or partially) due to either loss of calibration of the sensing elements or faulty sensor nodes (e.g., see graph in [13]). This contamination may gradually accumulate over a period of time (gradual drift), or occur in one-off transients. Such errors need to be detected at their source in real time and corrected, in order to collect reliable data from the sensor network deployments. Further more, there is a need to automatically detect specific events of scientific interest in the monitored environment, for example, cold water intrusions. Once these events occur, we need the ability to automatically adjust the sampling frequency and type of measurements collected in response to the event of interest.

The general problem of detecting interesting changes from the normal observed behaviour in sensor measurements is known as anomaly detection. An anomaly can be caused by an unusual change in the phenomena such as water temperature and nutrient concentration, or by faulty sensors: that cause incorrect measurements, or even by malicious events such as security attacks in sensor networks [14]. Important challenges for the management of sensor networks in complex environments such as the GBR are the detection, inference, reporting and correcting of anomalies.

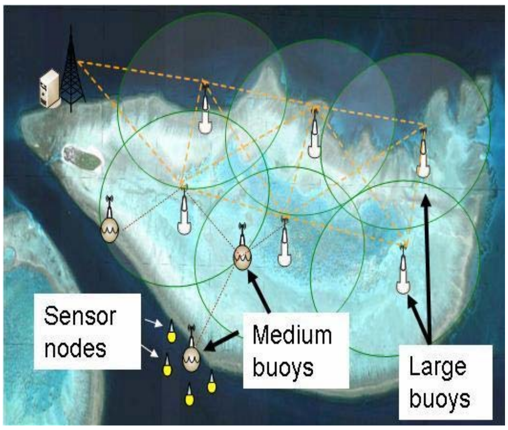


Figure 1: Sensor network schematic for planned deployment in Heron Island, GBR Australia

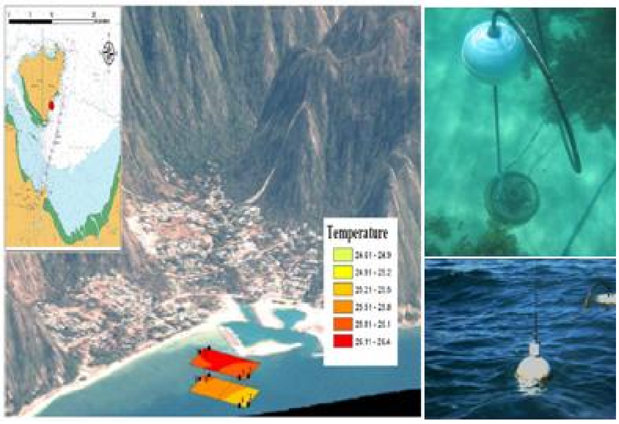


Figure 2: Sensor nodes used in deployment in Nelly Bay, Magnetic Island, GBR Australia [13].

3. Wave Dynamics and Connectivity in Sensor Networks

The first attempt of wireless sensor network deployment in GBR was in 2007 in Nelly Bay, Magnetic Island. A preliminary wireless sensor network test bed was deployed in Nelly Bay, Magnetic Island (146 51’ 9” E 19 9’ 52”S) by Bondarenko *et. al.* [13] (Refer to figure 2). The sensor network consists of two sensor arrays that comprise four moorings, each having seven temperature sensors vertically positioned below the ocean surface 2m apart [15]. In this deployment the mooring consisted of floating buoys, fixed at the ocean floor with the help of cables as shown in figure 2.

One of the problems experienced in this deployment was maintaining connectivity between nodes and shorter life time of the network. Main reason for loss of connectivity between nodes was the movement of antennas caused by ocean wave dynamics. This causes the communicating antenna of a node to move around and sometimes losing the line of site of the other node. Further more, once the communication is lost with the other nodes, the current node continuously searches to establish communication and by doing so it is exhausting its battery power. This is a communication intensive operation that results in fast energy drainage in the node leading to shortening of the life time of the network. Hence it is important to device an adaptive communication scheduling scheme to maintain the connectivity of the sensor nodes during the operation, taking into consideration the mobility of the nodes induced by the wave dynamics. In this regard we look at different scenarios of network connectivity issues due to antennae movements and wave dynamics in more details.

Consider sensor network deployed in an area of interest in the marine environment such as the Heron Island as shown in Figure 1. The network consists of *n* nodes and monitors ocean parameters such as sea temperature at various depths. The nodes are deployed using floating buoys. Consider the number of nodes *n* is just enough to provide full coverage of the area of interest. However, during its operation the nodes will experience mobility due to wave motion in the sea. This will results in loss of connectivity in some of the nodes in the network due to misalignment of antennas between communicating nodes. This will result in loss of valuable data collected by those sensors. In order to minimise the loss of data and connectivity, a scheduling scheme is required at each node to identify the correct time to communicate the data to the other node. The problem we investigate here is how to adoptively schedule the nodes for communication by monitoring its own mobility in order to maximise the success of communication and minimise the unsuccessful tries. This requires a study of dynamics of the wave to arrive at a suitable time window for communication. We call this suitable time window for communication as "*time window of opportunity*". That is, during this *time window of opportunity*, a sensor would have higher opportunity to successfully transmit the data to the other node. When the *window of opportunity* is absent, the sensed information can be stored on the node itself and sent when the communication is established.

A simple solution that comes to our mind for the problem of maintaining the connectivity in the network is to deploy *redundant* nodes in the area of interest that function as relays to maintain connectivity. However, this has two drawbacks. Firstly, deploying redundant nodes will block the marine navigation and also pollutes the marine environment. Clearly this needs to be avoided. Secondly, each introduced redundant node has to have a proper mooring and floating buoy with antennae at the surface, which not only crowds the area but also significantly increases the cost of deployment. Hence a viable solution would be to provide an adaptive scheduling scheme for the nodes to ensure efficient data transfer achieved in the sensor network.

The adaptive solution requires measuring the wave dynamics in real time and discovering the *time window of opportunity*. This comprises two components: (1) a means of measuring wave movements. This can be achieved by using an accelerometer at each sensor node to measure the displacement at each instance; (2) a wave dynamics model which can be used to arrive at the correct *time window of opportunity* in order to start data transmission. Modelling of wave dynamics requires analysis of wave movements. Mobility of the buoys (and hence the sensor nodes) due to wave dynamics consist of following three basic movements.

- Radial displacement or vertical movement of the buoy (R-displacement). This is caused by the sea tides. This is perpendicular to the surface of the sea.
- Tangential displacement or horizontal movement of the buoy (T- displacement). This is caused by the waves in the sea which is along the surface of water
- Slanting of the buoy (S-displacement). This is due to the movement of the buoy due to the change in centre of mass of the buoys. This causes the antenna of the sensor node to tilt and hence resulting in reduced range of communication and polarisation issues.

Based on different combinations of the above three basic displacements of the buoys, different complexities can be defined. In this paper it is assumed that the omni directional antenna is used in each sensor node for communication.

Definition 1: *First order displacements*: Buoy experiences only R or T or S movement independently. Figure 3 shows three basic movements of a buoy on sea water. In R-displacement a buoy experiences only vertical displacement due to wave tides. In T-displacement a buoy will move within a circle or an ellipse in the horizontal plane. Note that the buoys are fixed to the ocean floor by means of cables. Therefore, the buoy will move within a defined circular or elliptical plane. In S-movement, buoy experiences a tilt about its position and hence the antenna will traverse a cone about its position.

Definition 2: *Second order displacement*: Buoy experiences combination of pairs of movements. This consists of three cases, namely: R-T movement, R-S movement and T-S movement. Figure 4 shows these three possible movements of a buoy.

Definition 3: *Third order displacement*: Buoy experiences combination of all three movements (i.e., R, T and S together). Figure 4 shows the possible path of the buoy movement. This is a more realistic situation and is observed that most of the time the sea exhibits a third order displacement.

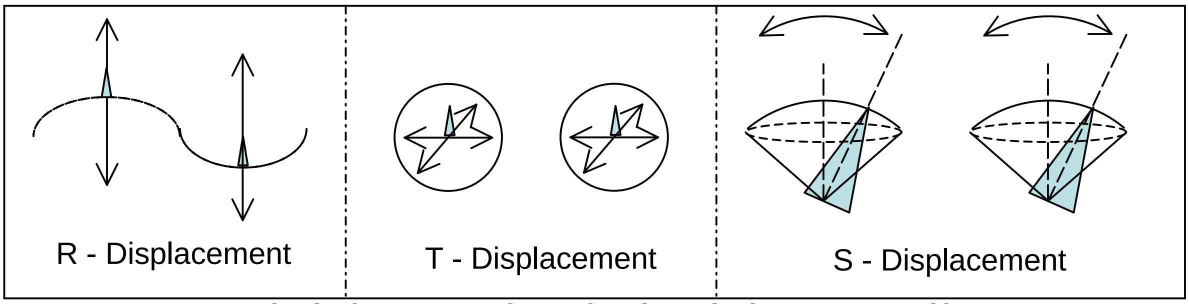


Figure 3: First order displacement on a buoy. Three basic displacements caused by wave motion.

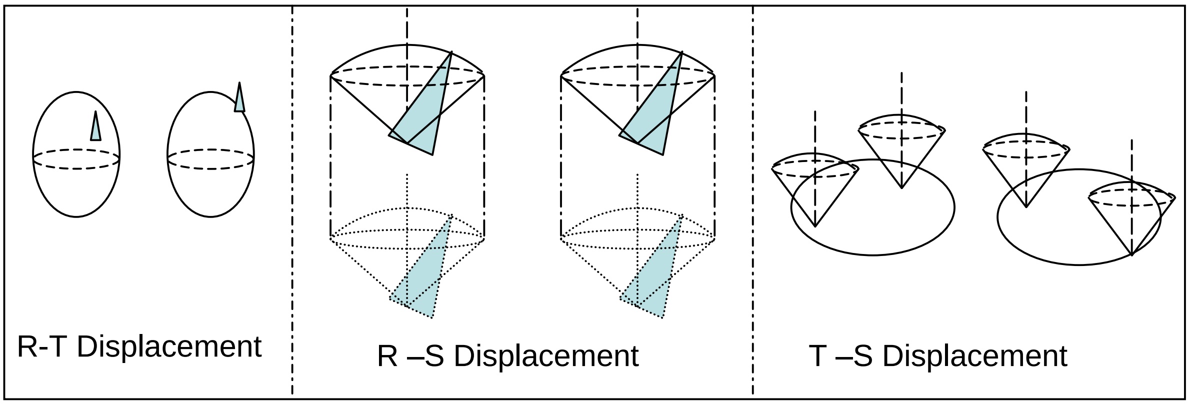
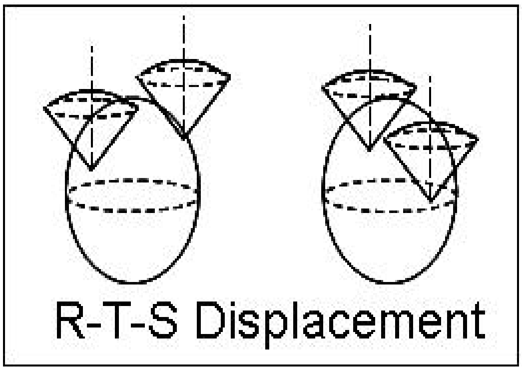


Figure 4: Second order displacement of a buoy.



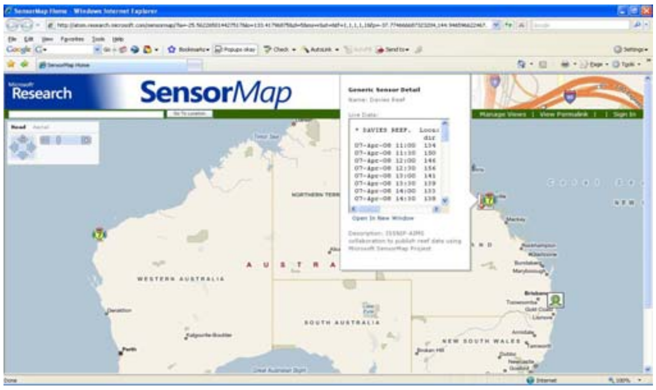


Figure 5: Third order displacement of a buoy.

Figure 6: Davis reef data published on the Microsoft SensorMap.

plexities of displacement, the distance between two buoys d_b can be computed mathematically in terms of the initial distance between two buoys (at deployment instance), the length of the antenna, the maximum tangential displacement, maximum radial displacement and the slant angle. Using the antenna range (of communication) and the calculated d_b, a set of possible distances for which successful communication can be established can be computed. That is, a set of R, T and S positions can be obtained for which successful communication is achieved. Therefore, the *time window of opportunity* can be obtained as the time window within which the R, T and S positions gives a d_b for successful communication. As mentioned earlier, each node uses accelerometer measurements to obtain their current R, T and S positions (with respect to the original coordinates) and hence to arrive at the *time window of opportunity.*

In the above discussions, it is assumed that there is line of sight. In case line of sight is absent, it results in complete loss of communication between those nodes. Such occurrence of waves cannot be detected by the accelerometers at those sensor nodes. Hence this scenario cannot be accommodated in the above analysis. During such events the data at a sensor node can be logged in memory to prevent any data losses.

First step towards modelling of these wave dynamics is to collect wave movement data. For this purpose, a test bed is planned for deployments which consist of iMote2 sensor nodes with accelerometers. This will be deployed in the AIMS pier to collect three dimensional acceleration data with their communication logs for a period of one month. This data can be used to arrive at the above mentioned basic movement measurements and hence to evaluate the model.

4. SensorMap for the GBR

The SensorMap for The Great Barrier Reef project intend to provide a valuable interface between the sensors and higher level objectives of multidisciplinary research teams around the world, from sensor networks researchers to marine biologists. Utilising the core infrastructure associated with a sensor network deployment currently in progress on the GBR, this project aids in the collection and dissemination of a diverse range of unique sensor data.

Data collected from some of the existing AIMS autonomous weather stations are made available via Microsoft SensorMap [16], namely; Davis reef, Agincourt reef and Ningaloo reef. Figure 6 shows the reef data from Davis reef published on SensorMap. Other reef data can be viewed from [17, 18]. Sensor network data from the planned deployment at Heron Island will be made available via SensorMap in future.

5. Conclusions

Recent developments in technology together with widely observed climate change phenomena have revealed coral reef ecosystems as critical areas greatly susceptible to impact of global climate variations as well as other man-made influences. They have also been tipped as early indicators of such events. The need to understand and protect such delicate ecosystems has created an urgent demand for the sensor networks technologies to be deployed in order to perform essential environmental monitoring. This data can then be analysed by higher level systems such as a semantic web to eventually provide predictive information on destructive events such as coral bleaching. This paper analyses the challenges faced by sensor network deployments in the marine environment particularly the Great Barrier Reef, where harsh marine conditions are often prevalent. Further, we look at modelling wave dynamics using accelerometer data to find the *window of opportunity* for data transmission between nodes. SensorMap publishing of data from existing AIMS weather station is also provided. Future work includes deploying a test bed at AIMS pier for collecting and verifying sensor scheduling scheme. The deployment of sensors in the Heron Island and publishing the real time data from Heron Island sensor networks on the Microsoft SensorMap is also planned.

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References

[1] R. Berkelmans, G. Death, S. Kininmonth, and W. Skirving, “Comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns and predictions”, Coral Reef 23, 2004, pp 74–83.
[2] M. Furnas, “Catchments and corals: terrestrial runoff to the great barrier reef.”, AIMS, Townsville, 2003.
[3] M. Borsuk, C. Stow, and K. Reckhow, “Integrative environmental prediction using bayesian networks: a synthesis of models describing estuarine eutrophication”, Integrated Assessment and Decision Support, (2), 2002, pp102–107.
[4] S. Wooldridge and T. Done, “The use of bayesian belief networks to aid in the understanding and management of largescale coral bleaching”, MODSIM, 2003, pp 614–620.
[5] http://www.xbow.com/Home/HomePage.aspx
[6] http://www.ambient-systems.net
[7] http://www.reefgrid.org/sensors/
[8] Zhao, F., Liu, J., Liu, J., Guibas, L., and Reich, J. 2003. “Collaborative signal and information processing: An information-directed approach”. Proceedings of the IEEE 91, 8, 1199 – 1209.
[9] L. van Hoesel, P. Havinga, “A lightweight medium access protocol (LMAC) for wireless sensor networks: reducing preamble transmissions and transceiver state switches”, in: Proceedings of the International Conference on Networked Sensing Systems (INSS), 2004.
[10] G. Mathur, P. Desnoyers, D. Ganesan, and P. Shenoy, “Ultra low power data storage for sensor networks,” in Proc. of the fifth intl. conf. on Information processing in sensor networks. USA: ACM Press, 2006, pp. 374–381.
[11] O. Gnawali, K.-Y. Jang, J. Paek, M. Vieira, R. Govindan, B. Greenstein, A. Joki, D. Estrin, and E. Kohler, “The tenet architecture for tiered sensor networks,” in Proceedings of the 4th international conference on Embedded net-worked sensor systems. New York, NY, USA: ACM, 2006, pp. 153–166.
[12] P. Kulkarni, D. Ganesan, P. Shenoy, and Q. Lu, “Senseye: a multi-tier camera sensor network,” in Proceedings of the 13th annual ACMinternational conference on Multimedia. New York, NY, USA: ACM, 2005, pp. 229–238.

[13] Olga Bondarenko, Stuart Kininmonth and Michael Kingsford, “Underwater Sensor Networks, Oceanography and Plankton Assemblages”, in the Proc. of International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP 2007), pp 657-662, (Melbourne, Australia), 2007.
[14] A Perrig, J Stankovic, and D Wagner, “Security in wireless sensor networks”, in Wireless Personal Communications, vol 37, no 3-4, 2006
[15] Olga Bondarenko, Stuart Kininmonth and Michael Kingsford, “Coral Reef Sensor Network Deployment for Collecting Real Time 3-D Temperature Data with Correlation to Plankton Assemblages”, in the Proc. of International Conference on Sensor Technologies and Applications (SENSORCOMM 2007), pp 204-209, (Valencia, Spain), 2007
[16] http://research.microsoft.com/nec/senseWeb/
[17]http://atom.research.microsoft.com/sensormap/?la=-25.562265014427517&lo=133.41796875&zl=5&ms=r&st=&tf=1,1,1,1,1&fp=-37.774666687323204,144.946596622467.
[18] http://www.ee.unimelb.edu.au/ISSNIP/projects/GBRproject/GBR.html
[19] http://www.nist.gov/.