Forecasting Red Tides Using a Novel Multi-Metric Adaptive Routing Algorithm in Underwater Wireless Sensor Networks

K.Seena Naik, Dr. Ramachandra, M.V.Brahmananda Reddy

Abstract— **The red tide phenomenon has resulted in millions of whelk, fish and oyster deaths in ocean water. Current approaches to monitor red tides include satellite imagery, onboard monitoring and monitoring using buoys. These approaches capture surface information at the expense of huge cost. A cost-effective alternative to monitor red tides is deploying terrestrial-underwater Wireless Sensor Networks to monitor and forecast red tides. A novel multi-metric adaptive routing algorithm is implemented. Multiple metrics such as packet age, depth of the sensor node, average energy level of the network, number of hops to the base node are considered. Depending on the value of the calculated metrics; an almost ring routing technique, centralized routing technique, or distributed routing technique is deployed. The metrics are reestimated after the data is sent. Once the data reaches the base node, a comparison is made with dynamic threshold values for the contributing factors and, accordingly, a decision is made and a red tide warning is issued, if needed.**

Index Terms— **Underwater Wireless Sensor Networks, Routing, Algorithm, Red Tides**

I. INTRODUCTION

Several reports in the recent past reveal the brutal after-effects of red tide phenomenon resulting in fish deaths and whale deaths [1] [2] [3] [4]. The vicious effects of red tides are experienced in different countries across the world including Australia, India, Italy, Ireland, Guatemala, En gland, the United States, Canada and Brazil [5].
Phytoplankton forms the food for higher living marine species in the hierarchy (i.e. fishes etc.). Phytoplankton in large quantity displays green light attributing to the chlorophyll. Some phytoplankton is determined by the discoloration of water due to huge density of pigmented cells. The presence of dinoflagellates of the genus Alexandrium and Karenia makes phytoplan kton look red in color. These phytoplankton which are generally referred to as „algal blooms ,are termed red tides. Reasons for the occurrence of red tides are largely unknown to the scientific community. However, few reports have attributed this to ever changing ocean temperatures in combination with lack of wind and rain [6].
Significant research has been invested currently in Underwater Wireless Sensor Networks (UWSNs) considering the potential of underwater applications. UWSNs potentially have wide range of applications in military, ocean environment conservation and target tracking. UWSNs are also useful in disaster management and monitoring earthquakes underwater. Unlike terrestrial Wireless Sensor Networks, which uses radio communication, acoustic communication is used mostly (depending on the application) in UWSNs. This is due to issues such as attenuation, band width and energy conservation. Other issues such as high latency and nod e mobility are well documented [1 6]. It is evident from these issues that routing protocols designed for terrestrial Wireless Sensor Networks are not suitable for UWSNs and also predominantly due to energy concerns. [17] details the energy analysis of routing protocols for underwater wireless sensor networks.

The paper is categorized as follows: Section 2 presents background and related work and Section 3 details the proposed multi-metric adaptive routing algorithm and its features. Section 4 presents the forecasting approach and Section 5 lists the future work of the research.

II. Background and Related Work

Current approaches to forecast red tides include research by Kim et al. in Korea [7], red tide detection using MODIS satellite images [8] and algal bloom forecast using ocean model HIROMB and biogeochemical model SCOBI [9]. National Fisheries Research and Development Institute (NFRDI) of Korea began monitoring red tides in 1972. However, as red tides became more frequent in mid-nineties, they were monitored using vessel cruising, by patrolling coastal waterfront, by aircraft observation and by remote sensing. NFRDI used fuzzy modeling for analyzing meteorological factors like wind, precipitation and sun light intensity. Researchers note that the three-dimensional physical-biological models that were developed to predict red tides are highly constrained by data [7]. [8] evaluates three approaches based on k-nearest neighbors, random forests and support vector machines for detecting red tides utilizing MODIS satellite data. This research focuses on distinguishing red tides from non-toxic algal blooms and other noise in satellite images.
Lake et. al present a biogeochemical and ocean forecasting model of algal blooms in Baltic Sea in [9]. High Resolution

Manuscript received Aug 30, 2014
K.Seena Naik, Department of CSE, S.K University, Anantapur, India
Dr. Ramachandra, Professor, Department of CSE, S.K University, Anantapur,India
M.V.Brahmananda Reddy, Department of CSE, GITAM University, Bangalore,India

Operational Model for the Baltic Sea (HIROMB), a three-dimensional baroclinic model is used as ocean model. Swedish Coastal and Ocean BIogeochemical model (SCOBI), which is uni-dimensional, constitutes the biogeochemical model that attributes for oxygen, nitrate, ammo nia, phosphate, phytoplankton, zooplankton, detritus, benthic inorganic nitrogen and benthic inorganic phosphorous. Lee et. al propose HydroCast, a hydraulic pressure based anycast routing protocol to route information to surface buoys in [10]. This research uses a one-dimensional geographic anycast routing in vertical direction to the ocean surface using depth information from pressure sensor. Onboard monitoring is implemented in this research. While onboard monitoring is relatively accurate approach, field sampling is required. Human intervention is essential to monitor measurements. The measurements obtained by this approach are less time-sensitive. Most importantly, this technique largely depends on weather conditions. On a bad-weather day (storms), observing measurements ship-borne is a very challenging task and almost impossible. Another approach to monitor red tides is buoy-line monitoring which requires very high precision sensors and calibrate sensors. Anti-corrosion protection of sensors becomes essential and inevitable.

Routing in Underwater Wireless Sensor Networks (UWSNs) has been explored in recent years. Vector-based forwarding protocol for UWSNs was addressed in [11]. This is a position-based routing protocol where sensor nodes close to the vector from source to destination are eligible to forward the information. This ensures only few nodes participate in routing and hence relatively less energy consumption. [10] tries to address expensive distributed localization in designing a pressure routing protocol for UWSNs. This research assumes that data propagation from sensor nodes to surface nodes is purely vertical. To handle localization problem, it assumes a one-dimensional geographic anycast routing approach that uses depth information from the pressure sensor.

Building on research in [11], [12] introduced vector based forwarding protocol for every individual forwarder instead of one single source to destination routing vector in [11]. Hop-by-hop vectors help overcome issues like small data delivery ratio for sparse networks and sensitiveness to routing-pipe radius threshold. Hop-by-Hop Dynamic Addressing Based Routing protocol aims to maximize delivery ratio, minimize the message latency, and optimize energy consumption in [13]. This research implements both radio and acoustic energy models. While the radio energy model is used for communication between surface buoys, acoustic energy model is used for underwater communication. Routing is made possible in two phases, while the routes are created in the first phase after assigning Hop IDs to floating nodes, information is delivered using the assigned identification IDs. An energy-efficient routing protocol for UWSNs is proposed to reduce delay and ensuring energy efficiency in [14]. Data aggregation tree is implemented to reduce the energy consumption. Nodes send their interest to be a decision node in the first step and the decision node is selected in the second step. Data aggregation tree is reconfigured in the third step and data is then transmitted. A depth-based routing protocol is described in [15] that does not use a localization service to find the position of the nodes and that is capable of taking advantage of multiple-sink architecture in UWSNs. Packet forwarding decision is made by a sensor node based on its depth information and depth of the node that the packet was sent from. The receiving no de forwards the packet only if its depth is lesser than sender nodes depth as it will be closer to the sink node.

III. Routing Algorithm

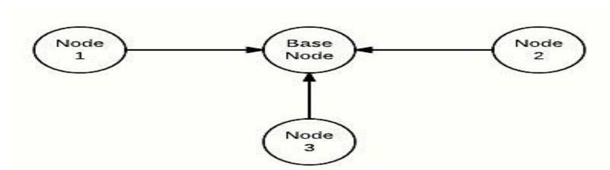
Network Topology

The participating nodes in the underwater wireless sensor network to b e d eployed are assumed to be in water. Hence, they co mmunicate among them using acoustic communication. Base node is assumed to be floating on water surface. Participating nodes communicate with base node using acou stic commun ication. Base node is equipped with both radio and acoustic modems.

3.1) Routing Approaches

a) Centralized ap proach

Participating nodes sense information and send the data

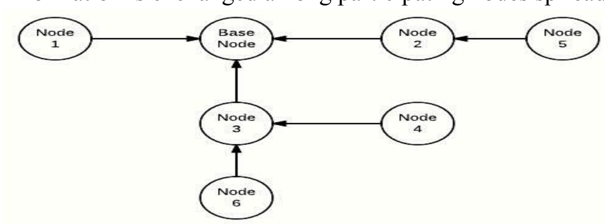


directly to the base node.

Figure 1. Centralized routing approach

b) Distributed approach

Information is exchanged among participating nodes sp read

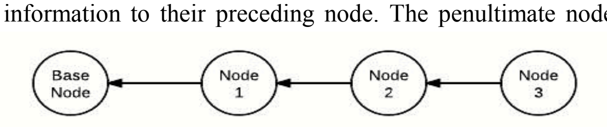


acro ss layered architecture

Figure 2. Distrib uted routing approach

c) Almost-ring approach

The base node signals final node in the network to begin the almost-ring algorithm. Participating nodes then send information to their preceding node. The penultimate node



then sends to the base node.

Figure 3. Almo st-ring routing approach

3.2 Multi-Metric Adaptive Routing Algorithm

Instead of choosing single factor like depth of the node or battery level, multiple metrics such as energy level of the node, average energy level of the network, packet age, and number of hops to the base node are considered to select a routing technique. This is due to the fact that a UWSN is more likely to be influenced by multiple factors than a single factor. We do not consider node mobility, another significant factor affecting co mmunication in UWSNs, in our work. By and large, we assume no des to be static in the underwater environment.

a) Energy level of the node

UWSN nodes use batteries for generating p ower and cannot be recharged using solar energy in underwater environment. Hence, any decision regarding routing must involve energy level of the node to estimate the routing approach.

b) Average energy level o f the

network Even if more than one-third of the nodes do not have sufficient energy (poor/moderate energy levels), using a pre-determined routing approach will conserve little energy. Hence, depending on the average energy level of the network, routing techniq ue decision can be made. The average energy level of the network is estimated in the range [0 , 100].

c) Packet age

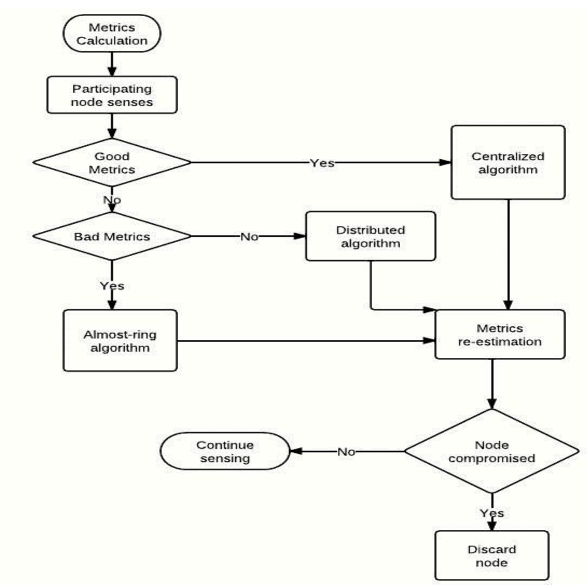
Packet age information is impo rtant to understand latency in the UWSN.

d) Number of hops to the base node

All nodes are, usually, not equidistant from the base node. In a centralized approach where participating nodes send information directly to the base node, it can be assumed that a node with higher hop count requires more energy to send a packet.

e) Depth o f the node

Nodes are deployed at different depths underwater. For a given energy level, nodes closer to the base node (less depth) are more likely to send their data successfully given the bandwidth and energy constraints in a UWSN. Node depth information is useful for adapting routing strategy



depending on the average energy level in the netwo rk.
The flowchart of the routing algorithm is presented in Figure 4.

Figure 4. Multi-metric Adaptive Routing algorithm

Additionally, the network can operate in reliability mode or greedy mode. In reliability mode, an effort is made to ensure information is communicated efficiently saving energy. In greedy mod e, data packets at the participating nodes are sent to the base node at the expense of energy. Nodes are con side red to be compromised if it is attacked by an intruder or if it has empty charge

3.2.1. Adaptive Routing

The mean metrics level of the network is estimated after initial metrics calculation at all the nodes. Theme an metrics are categorized as good, average and poor metrics. Good metrics level ranges from 67- 100, average metrics level ranges from 34-66 and poor metrics level ranges from 1-3 3. Good node metrics mean that a node is in good condition for using centralized routing approach. An almost-ring routing approach is chosen in case of poor node metrics because less energy is required for a node to transmit information to its preceding node. A distributing ro uting approach is chosen when the metrics level is average.

3.2.2 Metrics Calculation

The performance of the nodes deployed underwater in a UWSN depends on multiple factors. These factors are packet age, depth of the deployed node, energy level of the node, average energy level of the network at a given instance and number of hops taken from a node to the base node. Metrics are calculated co nsidering packet age, energy level of the node and the nu mber of hops taken for the node to the base node. The metrics are estimated according to [21] as follows:

$$\textbf{Metrics, } M = a1A + a2E + a3H$$

where A represents packet age, E represents energy level o f the node and H represents the ho p count for a packet to reach the base node from current node.

3.2.3. Metrics Categorization

The range of metrics, M is defined to be [1-10 0] where 1 means lowest metrics level and 100 is highest metrics level possible. M values from 1 to 33 are termed bad measurements, M values from 34 to 65 are termed average measurements and M values over 65 are termed good measurements.

3.2.4. Modes of Opera tion

a) Reliability Mode

Node depth is measured in the range [1-100]. The routing algorith m changes as detailed:

Step 1: If node_depth < 34, for any value of average_energy_level, centralized routing approach is chosen.

Step 2: If node_depth > 65, for any value of average_energy_level, almost-ring routing approach is chosen.
S
tep 3: If 34 <= node_depth <= 65 ,

If average_energy_level < 30, almost-ring routing approach is chosen.
If average_energy_level > 65, centralized routing approach is chosen.
If 30 <= average_energy_level < = 65, d istributed routing approach is chosen.

b) Greedy Mode

In greedy mode, all participating nodes are eager to deliver the information to the base node. For all hop counts of the participating nodes, the centralized approach is followed .

IV. Forecasting Red Tides

Existing methods to forecast red tides include, as mentioned earlier, satellite imagery and buoy monitoring. As a cost-effective alternative to current approaches, Wireless Sensor Networks (WSNs) can be deployed to capture surface and sub-surface information. Terrestrial WSNs can be used to capture surface information and UWSNs can be used to capture surface and sub -surface information.

4.1. Contributing Factors

A contributing factor is a factor (temperature, humidity etc.) that influences red tides. Red tides are not caused by a single contributing factor. Multiple contributing factors in coordination with each other cause red tides. Meteorological measurements do not have definite measurement levels for red tides but they (sunlight, wind) propel the generation of red tides. Multiple contributing factors categorized as biological measurements, conservative measurements and meteorological measurements are responsible for the occurrence of red tides.

Biological Measurements

Biological measurements such as chlorophyll-a, dissolved oxygen and dissolved nitrate, phosphorous must be monitored regularly to notice the changes in ecological balance.

A. Chlorophyll-a

If chlorophyll-a measures 0 .06 mg/m^3 or less, normal conditions prevail. However, if the measurements cross 3 mg/m3, the scope for fish deaths is very high. Water turns red for high levels of chlorophyll-a.

B. Dissolved Oxygen

Presence of algae in massive quantities reduces the oxygen available in water eventually leading to choking of fish. Dissolved Oxygen (DO) levels are poor when they are below 4 mg/L and DO levels are normal for anything above 4 mg/L.

C. Dissolved or particulate organic nitrate and phosphorousPhosphate and nitrate levels when over 10 mg/L support the generation of red tides. Phosphate and nitrate levels over 10 mg/L are not suitable for marine life and restrict plant growth.

Conservative Measurements

A. Temperature

Some researchers have attributed changes in ocean temperatures (Global Warming) as a direct reason for red tide phenomenon. Monitoring ocean temperatures frequently is essential for forecasting red tides.

B. Salinity

Red tides increase rapidly for higher sunlight intensity when temperature is above 59º F, still wind and salinity levels lower than 5 ppt [20].

C. pH levels

For the bacteria to exist, pH levels must range in between 2 to 13. Water assumes acidic behavior for pH levels below 6 .5 till 0 and assumes behavior of a base for pH levels from 8 to 14.

D. Turbidity

Turbidity is the effect if particulate material which is floating in water. Normal levels of turbidity are 10 NTU. High concentration of algae results in high turbid water which eventually decreases the light intensity that reaches the depths of ocean water. This obstructs the growth of aquatic vegetation in underwater environment thereby destroying the food for marine species.

Meteorological Measurements

a)Wind

b)Precipitation

c) Sunlight Intensity

There are no definite levels of wind and precipitation to cause red tides but when in conjunction with other contributing factors such as chlorophyll-a, salinity, temperature and sunlight cause great damage. Sunlight alone does not cause red tides but when sunlight acts along with temperature above 59 F and salinity less than 5 ppt, red tide occurrence has greater possibility.

The information sent using the multi-metric routing algorithm described above reaches the base node through either centralized or distributed or an almost-ring approach. The base node checks the threshold of the contributing factors with the values received. The base node then reports the possibility of a red tide. Depending on the threshold levels, a) mild red tide warning or b) strong red tide warning is given.

Implementation

Considering that there is no existing underwater wireless sensor equipment, we will be relying on simulations to forecast red tides and to implement, verify the adaptive routing algorithm. Simulations will be performed in C language using MPI (Message Passing Interface). The threshold levels for contributing factors of red tides will be used as defined in the above section.

The routing algorithm described above evolves by learning from the behavior of the network and individual properties of nodes such as packet age and hop count to the base node. Depending on the
Average Energy Level (AEL ranges in [0, 100]) in the network, a routing approach is decided as packet progresses in the network. If AEL drops and changes threshold level after some data exchanges among participating nodes, a different routing approach is followed.

V. Future Work

Multi-metric adaptive routing algorithm for UWSNs considers metrics such as depth of participating nodes, packet age, and average energy level of the network, energy level of the participating node and hop count of a participating node to the base node. Considering node mobility in this context is a definite future work. Secure transmission of data is essential in military applications. Investigating the possibility of securing communication with a light-weight security protocol is another research direction. At present, only the floating nod e acts as a base node. A selection for base node based either on the node with highest ratio of initial and current energy levels or the node with highest metrics can be implemented.

Conclusion

Red tides have caused the deaths of millions of ocean species such as fishes, oysters and whelks. Satellite imagery is a costly solution for capturing surface information in the ocean water. Wireless sensor networks offer a cost-effective alternative solution for forecasting red tides to satellite imagery and buoy monitoring. We have proposed a novel multi-metric adaptive routing algorithm. Base node is equipped with both acoustic and radio modems and participating nodes are equipped only with acoustic modem given that they are deployed underwater. Based on the value of the metrics calculated, the algorithm adapts as an almost ring technique or a centralized technique or a distributed technique. Additionally, reliability mode and greedy mode of the routing algorithm are presented.

Acknowledgment

This work has been supported in part by NSF awards CNS-1004902 and CNS-0708573 and a Texas Research Development Fund grant.

Bibliography

[1] Adianto P. Simamora, Increasing red tides a threat to fish farming, Indonesia, The Jakarta Post – May 14, 2010. Last accessed at http://www.thejakarta post.com/news/2010/05/1 4/increasing -red-tides-a-threat-fish-farming.html, on October 19, 2010 at 4:20 pm.

[2] Bill Freedman, Red Tide – Marine Toxins and their effect. Last accessed at http://science.jrank.org/pages/5773/Red-Tide.html , on October 19, 2010 at 4:23 pm.

[3] Andrew R. Solow, Red Tides and Dead Zones – The coastal ocean is suffering from overload of nutrients, December 2004. Last accessed at http://www.whoi.edu/oceanus/viewArticle.do?id=2487&archives=true&sortBy=printed, on November 28, 2010 at 9:40 pm.

[4] Texas Parks and Wildlife, Red Tide Update – Current Status. Last accessed at http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/status.phtml, on October 19,2010 at 4:32 pm.

[5] Red Tide – A Harmful Algal Bloom, Montana State University.

[6] Texas Parks and Wildlife, Red Tides – Frequently Asked Questions. Last accessed at http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/redtide/faq.phtml, on October 19, 2010 at 4:31 pm.

[7] Kim, Hak Gyoon, Sam Geun Lee, Chang Kyu Lee, Wol Ae Lim, Korean Red Tide Monitoring and Prediction System.

[8] Weijian Cheng, Lawrence O. Hall, B. Goldgofm, Inia A. Soto, Chuanmin Hu, "Automatic Red Tide Detection from MODIS Satellite Images", In Proceedings of the 2009 IEEE International Conference on Systems, Man and Cybernetics, p. 1864-1868, 2009.

[9] Irene Lake, Lennart Funkquist, "Operational Forecasts of Algae Blooms in the Baltic Sea", IEEE/OES US/EU- Baltic International Symposium, 2008.

[10] Uichin Lee, Paul Wang, Youngtae Noh, Luiz F. M. Vieira, Mario Gerla, Jun -Hong Cui, "Pressure Routing for Underwater Sensor Networks", In Proceedings of INFOCOM 2010.

[11] Peng Xie, Jun-Hong Cui, Li Lao, "VBF: Vector-Based Forwarding Protocol for Underwater Sensor Networks", In proceedings of IFIP Networking, 2006.

[12] Nicolas Nicolaou, Andrew See, Peng Xie, Jun-hong Cui, Dario Maggiorini, "Improving the Robustness of Location-Based Routing for Underwater Sensor Networks", In Proceed ings of IEEE OCEANS 2007, 2007.

[13] Muhammad Ayaz, Azween Abdullah, "Hop-by-Hop Dynamic Addressing Based (H-DAB)2 Routing Pro tocol for Underwater Wireless Sensor Networks", In Proceedings of the 2009 International Conference on Information and Multimedia Technology, p. 436-441, 2009.

[14] Heungwoo Nam, Sunshin An, "Energy-efficient Routing Protocol in Underwater Acoustic Sensor Networks", In Proceedings of 2008 IEEE/IFIP International Co nference on Embedded and Ubiquitous Computing, p . 663-669, 2008.

[15] Hai Yan ,Zhijie Jerry Shi, Jun-Hong Cui, "DBR: Depth-Based Routing for Underwater Sensor Networks", In Proceedings of IFIP Networking, May 2008.

[16] Jun-hung Cui, J. Kong, M. Gerla, S. Zhou, "Challenges: Building Scalable and Distributed Underwater Wireless Sensor Networks (UWSNs) for Aquatic Applications", UCONN CSE Technical Report: UbiNet-TR05-02, January 2 005.

[17] Mari Carmen Domingo, Rui Prior, "Energy analysis of routing protocols for underwater wireless sensor networks", Journal of Computer Communications (Elsevier) 31 (6) (2008), pp. 1227–1238.

[18] E.M. Sozer, M. Stojanovic, J.G. Proakis, "Underwater Aco ustic Networks", IEEE Journal of Oceanic Engineering 25(1) (2000) 72-83, 2000.

[19] W. B. Heinzelman, A. P. Chandrakasan, H. Balakrishanan, "An application-specific protocol architecture for wireless microsensor network s", IEEE Transactions on Wireless Communications, vol.1, pp. 660670, 2002.

[20] EcoCheck, Assessing and forecasting ecosystem status – HAB Indicator Details (Methodology).Last accessed at http://www.ecocheck.org/forecast/chesapeake/2010/indicators/microcystis/\#\ _Methodology,on October 19, 2010 at 4 :49 pm.

[21] Zheng Guo, Gioele Colomb i, Bing Wang, Jun-Hong Cui, Dario Maggiorini, Gian Paolo Rossi, "Adaptive Routing in Underwater Delay/Disruption Tolerant Sensor Networks", In Proceed ings of the Fifth Annual Conference on Wireless on Demand Network Systems and Services, 2008.

[22] Leonid Maksimovich Brekhovskikh, Urii Pavlovich Lysanov, "Fundamentals of ocean acoustics",New York: Springer, 1982.