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EH-DBR: Energy Harvesting Depth Based Routing for Underwater Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are network of physical small sensors which are interconnected through wireless links. WSNs are ubiquitous in diverse types of environment such as air interface and underwater acoustic communication. WSNs are responsible for collecting data, accomplishing appropriate operations on it and if required then relay it to the sink node. WSNs had many issues and challenges specifically in underwater wireless sensor network (UWSN). Secondly there is an issue of network life time as the sensor nodes have limited battery and it is challenging to replace it frequently specially in UWSN. An important challenge in the performance of the DBR is the energy constraint due to limited battery life time, which can cause the entire network to go down. In this paper, we propose an Energy Harvesting Depth Based Routing Protocol (EH-DBR) protocol. Our proposed protocol (EH-DBR) sensor node harvest and store power via external acoustic source in the form of packets. The key advantage of our protocol is that its lifetime will be extended indefinitely. Moreover, our routing protocol can take advantage of DBR architecture without introducing extra cost. We conduct extensive simulations. The results show that EH-DBR can achieve very high packet delivery ratios due to long time performance.

Keywords: WSN, DBR, UWSN, Energy Harvesting, EH-DBR, Protocol

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1. Introduction

Underwater acoustic sensor network (UASN) is an application of Wireless Sensor Networks (WSNs) that is specially used for examining oceanic environment. The acoustic sensors collect the data and then using a routing scheme to relay it towards sink. The applications of UASNs are pollution examining, ocean current detection, submarine discovery, habitat monitoring, oil discovery, underwater surveys and management of seabed [1]. The acoustic wireless sensors with one or more sinks, on sea surface or dropped under water, organize the basic body of UASN. Sink has normally less power constraint, but the acoustic sensors have limited battery life [2]. The role of a sink on a sea surface is to gather information (useful data) and forward it through radio link to the fusion centers for further processing. Sinks are equipped with sound and radio

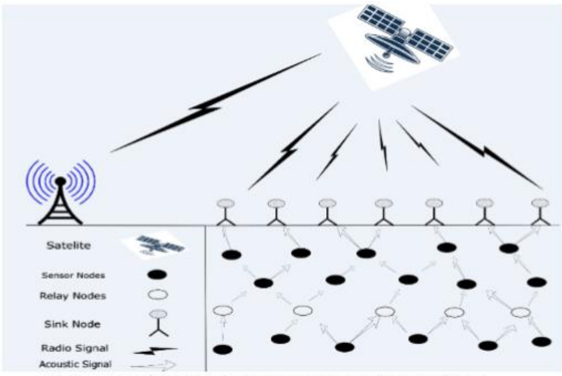

Figure 1: Underwater Sensor Network Architecture

modems along with GPS module. Every sensor node, in Sensor Equipped Aquatic (SEA) Swarm architecture, examines the nearby underwater activities and routes the appropriate information to sink using multi hop routing. The general architecture of UWSN is given in figure 1.

2 Node Architecture

As shown in Figure 2 the EH-DBR node architecture consists of four fundamental units harvesting unit, power unit, communication unit, control sensing and processing unit

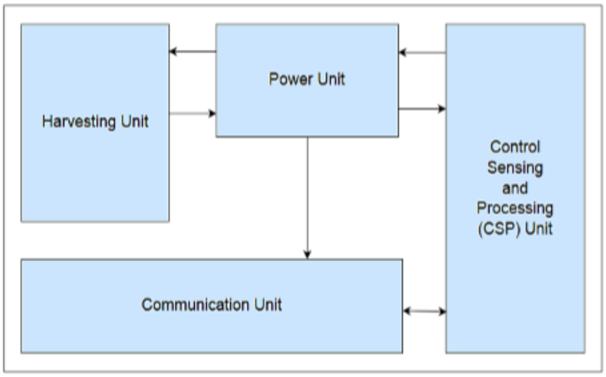

Figure 2: EH-DBR node architecture

a. Harvesting Unit

The harvesting unit receives the power through an array of n hydrophones, and the total power is accumulated in the power unit.

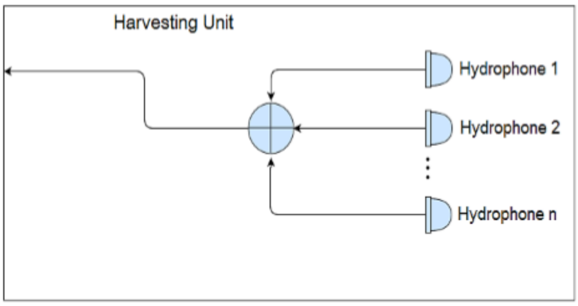

Figure 3: Harvesting unit

b. Power Unit

Power unit convert the power to DC, eithor to operate the sensor node or store it in capacitor for later use.

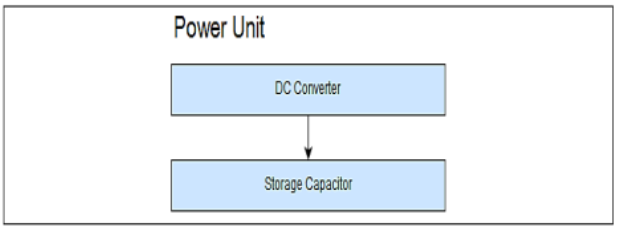

Figure 4: Power Unit

c. Communication Unit

The job of communication unit is to exchange the information among the nodes. It is consists of transducer which transmit and receive information and the control sensing and processing unit perform sensing and doing data processing.

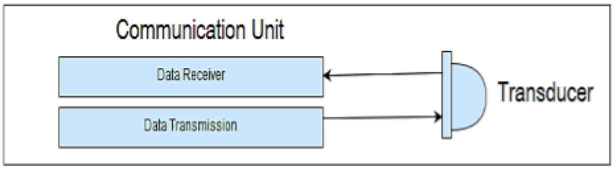

Figure 5: Communication Unit

d. Control Sensing and Processing (CSP) Unit

Control sensing and processing (CSP), unit performs sensing the Neighbor ACK, Neighbor request, and data packets when arrive at the node and doing necessary processing before transmitting.

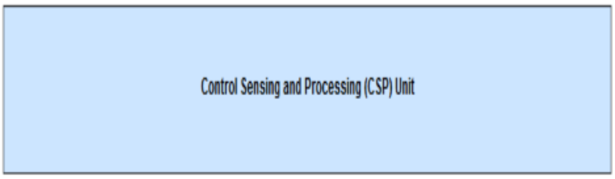

Figure 6: Control Sensing and Processing (CSP) Unit

3 Related Work

Among many research issues in this new and promising area (UWSN), Energy consumption, is one of the fundamental problems that need to be studied for constructing the UWSN protocol stack. Similar to land-based sensor nodes, underwater sensor nodes are usually powered by batteries, which are even harder to recharge or replace in harsh underwater environments. To extend the life span a significant amount of work has been done in terrestrial and underwater sensor network. The authors in [11] propose a heterogeneous network solution that is capable to balance energy dissipation among network nodes. In addition, the divide and conquer approach is exploited to evenly distribute number of transmissions over various network areas. An efficient forwarder node selection is performed to alleviate coverage and energy holes. Linear optimization is performed to validate the effectiveness of our proposed work in term of energy minimization. We can prolong life time by using energy harvesting concept. Energy harvesting (EH) is a method to extract some amount of energy from ambient source and periodically feed the sensor node in order to keep a network alive unlimitedly. The effective use of EH requires the harvest procedure ought to be incorporated into network style. A different researcher presents the mechanisms of energy harvesting that applicable to WSNs to overcome the problem. In [4], the authors review a variety of energy harvesting mechanisms that relevant to WSNs. They also discuss many newly offered energy prediction models for energy harvesting in WSNs and that have the capability to maximize efficiency in this regard. In [5], the authors incorporate the energy harvesting in the routing protocol of the WSNs. The worth of their work is proposed innovative routing protocol that not only considers the residual energy and prediction of harvested energy but also its wastage due to limited capacity of the battery in the routing protocol. The route has been selected on the basis of wastage of harvested energy which was not done previously. The authors considered the cost function regarding the consumption of energy for data transmission and wastage of harvested energy due to overcharging. In [7], the author worked out the problem of increasing the life time of wireless sensor network WSNs. They optimized the balance between the nodes in term of their wake up and sleep time. In this study they categorize the nodes in groups and the subsets of the groups that are active during some time slots or intervals while others remained in sleeping mode to conserve energy. They suggest a Linear Programming (LP) based results to resolve the activation schedule of sensor nodes at the same time as allowing them recharging chance. In [10], the author worked on Energy efficiency of wireless sensor network (WSNs). Energy efficiency means more work with less energy and also the performance of the network is improved by dividing the load equally in the entire node i.e. by balancing energy consumption. In energy efficient rounding protocols the node cannot only select the potential forwarding node on the basis of the depth but also it take in count the residual energy of the sensor. There is multipath for sending data to the sink in multiple sink network, the sink communicate with each other through radio frequency. The data reached to any sink would be considered that it is successfully delivered to its destination. Some sensor nodes are used frequently and its energy is consumed so much, so if we cannot apply the energy balancing techniques some nodes are permanently die. In [8], the author proposed a protocol named DBR. In DBR, a data packet has a field that records the depth information of its recent forwarder and is updated at every hop. The basic idea of DBR is as follows. When a node receives a packet, it forwards the packet if its depth is smaller than that embedded in the packet. Otherwise, it discards the packet. Obviously, if there are multiple data sinks deployed at the water surface, as in the multiple-sink underwater sensor architecture [4], DBR can naturally take advantage of them. Packets reach any of the sinks are treated as successfully delivered to the final destination since these water-surface sinks can communicate with each other efficiently through radio channels, which have much higher bandwidths and much lower propagation delays. To summarize, the main advantages of DBR are as follows.

1) It does not require full dimensional location information.

2) It can handle dynamic networks with good energy efficiency.

3) It takes advantage of multiple-sink network architecture without introducing extra cost.

The rest of the paper is organized as follows. In Section 4, we present.

Motivation towards EH-DBR. Section 5 shows Working Methodology of DBR. Flow Chart is shown in Section 6. In Section 7, EH-DBR Protocol and its equations are highlighted. We present the simulation results and its discussion in Section 8 followed by our conclusions and future works in Section 9. New innovation in routing schemes is needed and therefore we will propose the mathematical models inspired by the modeling by research community in literature review conducted which will help to cover those areas as well which have not been yet addressed.

4 Motivation

In Depth Based Routing (DBR), Protocol of UWSN full dimensional localization is not required. Therefore, we can achieve High Packet Delivery Ratio (PDR) on the basis of depth information i-e node near the sink will forward the packet. But to achieve this high ratio more energy will be consumed and underwater it is challenging to replace or recharge the batteries. So its life time will be effected i.e. if the energy of an individual node or a set of the nodes is depleted, it cannot enable the participation of these nodes to fulfill the connectivity requirement and hence disconnected from the remaining network which can cause the entire network blackout. Even if the network does not collapse by energy failure of few or more nodes, still it will degrade the efficiency and performance of the network. Keeping in mind these challenges, we proposed EH-DBR protocol. The basic idea of EH-DBR is when a node receives a packet; it forwards the packet if its depth is smaller than that embedded in the packet. Otherwise, it discards the packet. Obviously, if there are multiple Energy Harvesting data sinks deployed at the water surface, as in DBR [8], EH-DBR can naturally take advantage of them. Packets reach any of the sinks are treated as successfully delivered to the final destination since these water-surface sinks can communicate with each other efficiently through radio channels, which have much higher bandwidths and much lower propagation delays. We introduce the concept of Energy Harvesting in which sensors are powered by an external acoustic source, thereby extending lifetime indefinitely. We then investigate the performance of such networks in terms of sensing coverage and communication connectivity. The communication connectivity and sensing coverage provided by such networks under two fundamental scenarios whereby the single remote power source is either situated at the center of a spherical region or on the water surface, powering a conical region underwater In the former scenario it will be difficult to charge or replace Harvester batteries while in the later scenario we can charge or replace Harvester batteries.

5 Working Methodology For DBR

5.1 Holding Time Calculation in DBR

The holding time for a forwarding node is calculated based on d, where d is the depth difference between previous hope and current hope of the packet. Nodes with different depth will have different holding time. DBR selects the node with minimum depth from the water surface to forward the packet and suppress all other nodes in the transmission range in order to prevent the duplicate packets forwarding.

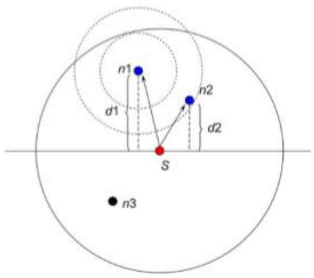

Figure 7: Forwarding Node Selection [8]

Equations (1) & (2) calculate the holding time for a node holding packet.

$$f(d) = \alpha \,.\, d + \beta \,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$f(d) = \frac{2\tau}{\delta} \,.\, (R - d), \delta \in (0, R] \ldots\ldots\ldots (2)$$

Where d is the depth difference of the current node and the previous one. R is the maximal transmission range of a sensor node.

5.2 Depth Threshold

For controlling the number of nodes involved in packet forwarding DBR introduced a global parameter, depth threshold dth. A node forwards a packet only if d > dth the values of dth can be positive, 0 or negative. If dth = 0, DBR selects all the nodes having smaller depth than the current node as qualified forwarding candidates. If dth = -R, DBR acts like flooding protocol (where R is the maximum transmission range). For larger values of dth DBR selects less number of nodes as qualified forwarding nodes which consumes less amount of energy and having lower PDR (packet delivery ratio). Oppositely for lower values of dth it selects larger amount of nodes with higher energy consumption and PDR.

6 Flow Chart

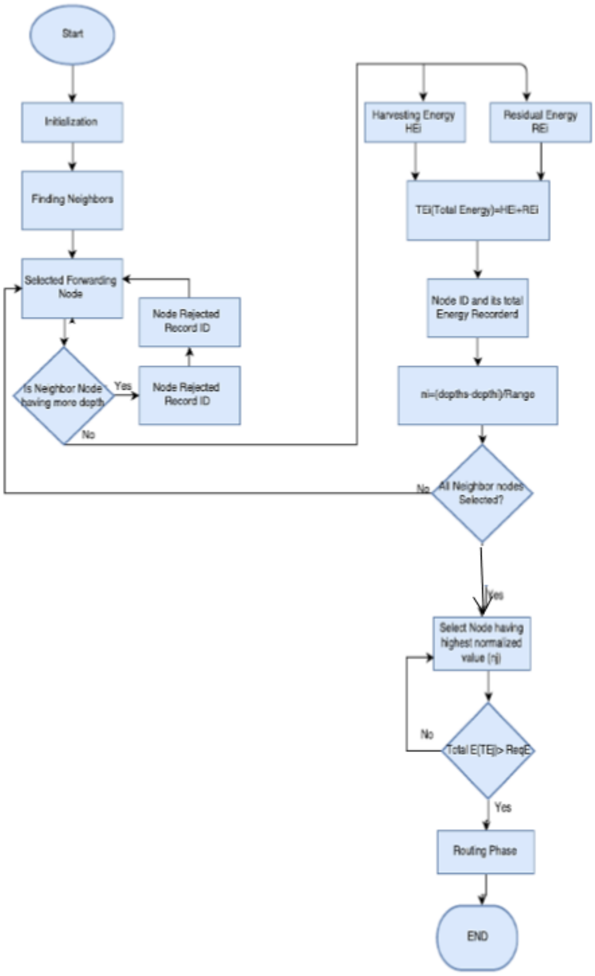

Figure 8: Flow chart for the EH-DBR scheme

7 EH-DBR Proposed Protocol

This section presents our proposed routing protocol EH-DBR for UWSN. We proceed with the following equations to define EH-DBR model.

$$Sl = 170.8 + 10\log_{10} Pelec + 10\log_{10}\eta + DI \ldots. (3)$$

Where Sl represent Source level in dB re 1 μPa at 1 m, P_{elec} is electrical input power, η is electro-acoustic power conversion efficiency and DI represent Directivity.

$$AL = 20\log_{10} R + \alpha(f)R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where AL represent Attenuation level, R is propagation range in m and α (f) represent the absorption coefficient.

$$RL = Sl - AL \ldots\ldots\ldots\ldots\ldots (5)$$

Where RL represent the received level in dB at a distance R from the source.

$p = 10^{RL/20}$……………………..…………(6)

p Represent the acoustic pressure on the hydrophone.

$$\boldsymbol{RVS = 20\,log_{10}\,M} \text{.................. } (7)$$

RVS is receiving voltage sensitivity level and M is sensitivity in Voltage per µ Pa.

$$V_{ind} = pM = (10^{\frac{RL}{20}})(10^{RVS/20} \text{……………………. } (8)$$

V_{ind} Represent the RMS induced voltage.

$$P_{available} = \frac{(n\,Vind)^2}{4nRp} = n\frac{Vind^2}{4Rp} \text{ ……………………………………….(9)}$$

$P_{available}$ is maximum power produced by n hydrophone.

$$P_{harv} = 0.7n\frac{10^{(RL+RVS)/10}}{4Rp} \text{ ……………………………………… (10)}$$

P_{harv} is the harvested power at each RPUASN node produced by n hydrophone.

$$r_s = [\frac{-\ln(1-\delta)V}{\frac{4\Pi N}{3}}]^{1/3} \text{ ………………………………………………(11)}$$

r_s is the sensitivity range of RPUASN node.

$$P_{req=\frac{0.7n}{4R_p}}10^{0.1}\left[170.8 + DI + 10\log_{10}\left(\frac{P_{elec}\eta}{R_{max}{}^2}\right) - \alpha(f)R_{max} + RVS\right] \text{ …………. (12)}$$

P_{req} is the required power to each sensor node .

Rearranging (12) gives the following condition for the Maximum range R_{max} :

$$\alpha(f)R_{max} + 20\log_{10}R_{max} = 170.8 + DI + 10\log_{10}\frac{0.7nP_{elec}\eta}{4R_pP_{req}} + RVS \text{ ………(13)}$$

$$r_s = [\frac{-\ln(1-\delta)R_{max}{}^3}{\frac{4\Pi N}{3}}]^{1/3} = [\frac{-\ln(1-\delta)}{N}]^{1/3}R_{max} \text{ ……………………………….(14)}$$

In the second deployment scenario, the source is assumed to be a circular piston type projector for which directivity index is related to the vertex angle of acoustic transmission (θ) by

$$DI = 20\log_{10}\frac{60\Pi}{\theta} \text{ ………………………………………………………………..}$$

The expression for the minimum sensing range r_s of a node is

$$r\ _s = \left[\frac{-\ln(1-\delta)R_{max}{}^3\left(1-\cos\frac{\theta}{2}\right)}{\frac{4\Pi N}{3}}\right]^{1/3} = \left[\frac{-\ln(1-\delta)}{2N}\alpha\left(1 - \cos\frac{\theta}{2}\right)R_{max}\right]^{1/3} \text{ . … (16)}$$

8 Results and Discussions

Assumptions of the network

1. Instead of conducting practical experimental research, a simulation environment will be created which will assume same underwater channel impairments as is the case in real-world scenario.
2. It will be assumed that the sensor nodes are static at their locations even with the movements of the water currents. However the sink linearly moves at different depth in underwater layers.
3. A network area of 2000 X2000 m2 will be assumed with a network deployment of 100 nodes randomly in this area.
4. 1st order energy minimization and harvesting model will be assumed for transmission and reception of sensor nodes as it is applicable for terrestrial

In figure 9 it is clear that end-to-end delay in EH-DBR protocol is minimum as compared to DBR. Figure 10 shows that energy consumption is minimized in EH-DBR. Moreover, figure11 shows an increase in packet delivery ratio PDR due to the fact that more number of alive nodes available as continues supply of harvested energy. Consequently, fewer holes created and the probability of packet drop decrease which is the major cause of improving PDR.

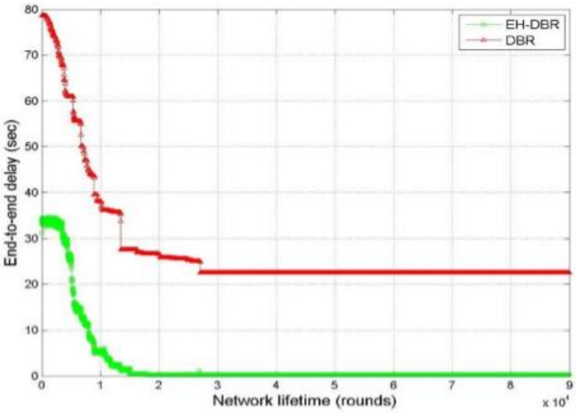

Figure 9: Average end-to-end delay Vs. Network Life-time

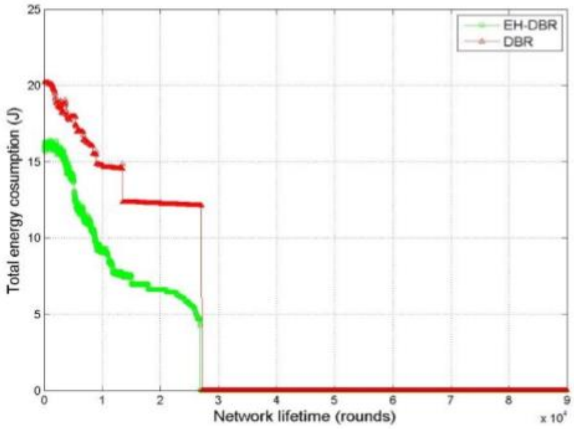

Figure 10: Energy consumption Vs. Network Lifetime

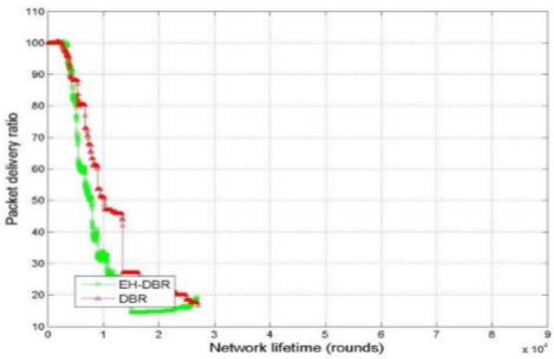

Figure 11: Packet delivery ratio Vs. Time

9 Conclusion and Future Work

In this article, we have proposed a routing protocol capable of utilizing and scheduling the harvesting energy from the underwater energy harvester. It is in turn improves the lifetime and end-to-end delay. Keeping in mind the energy scarcity, we designed routing protocol which is able to address the energy constraint challenge to their optimum levels. It will prove to be energy efficient with better throughput and enhancing the stability period of the network. Be computationally simple and implementable. Harvesters can be the part of the sensor node or it may be the separate entity which can provide energy wirelessly in the form of acoustic signal. The deployment of sensor nodes along with harvesters proves to be successful in term of maximizing the network lifetime. Moreover, the depletion of lesser depth node in DBR protocol is overcome due to continue harvesting energy supply from the harvesting system. In future, we will extend our work to design the movement model of the energy harvester that could be able to provide the required power to all the nodes at different location of the entire network. That will effectively eliminate the void hole or energy hole problem specially in randomly deployed UWSN.

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