A New Energy Efficient and Depth based Routing Protocol for Underwater Sensor Networks

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Abstract

Due to certain conditions of underwater environment, providing an efficient and scalable routing protocol in *underwater acoustic sensor networks* (UWSN), has many challenges. Communication in UWSNs is done through sound that compared with radio; it has lower speed, higher bit error rate, smaller bandwidth and higher and variable propagation delay. Also, in UWSNs, improving the energy efficiency is one of the most important issues since replacement or recharging of nodes batteries has a high cost. Moreover, many proposed routing protocols for UWSNs, use full information about the position of the nodes, that obtaining this information is a fundamental challenge in these networks. In this paper, a new protocol is proposed in which only the depth information of the nodes used in the routing process. Also, to balance the overall energy consumption and thereby increase the network lifetime, residual energy of the nodes considered in the routing calculations. The protocol is compared with DBR protocols using NS2 simulator. Our simulation results show that the proposed method not only improves the overall energy consumption of the network, the end-to-end delay is also reduced.

Keywords: underwater sensor networks, routing protocol, energy efficiency.

Introduction

Various factors such as geological processes in the ocean, study on water characteristics including temperature, salinity, oxygen levels, bacteria and other water contaminants such as water-insoluble material (Heidemann, Stojanovic, & Zorzi, 2011), detecting mines, forecasting and climate change monitoring, study the effects of human activities on marine ecosystems (ISIK, 2007), discovery of underwater oilfields, tracking mammals, fish and other micro-organisms (Deepika, 2005), disaster Prevention: Tsunami (Abdul, & Dongkyun,2012), and many other factors has caused the motivation for the development of underwater wireless sensor networks. UWSN consists of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. Using radio in UWSN, due to high attenuation and requiring large antenna about 0.5m (Ayaz, Baig, Abdullah, & Faye, 2011), is not suitable. So the sound technology is used in communications. Furthermore, get precise location information of sensor nodes, is another challenge that must be overcome (Ayaz, Baig, Abdullah, & Faye, 2011, Akyildiz, Pompili, & Melodia, 2004, Sehgal, David, & Schonwalder, 2011). GPS that can accurately estimate the position of sensor nodes in wireless networks does not work very well in underwater environments. Because GPS uses 1.5GHz bandwidth and these waves do not propagate in the water (Ovaliadis, Savage, & Kanakaris, 2010, Liu, & Wei, 2011). Many researches have been done about physical layer in UWSN. However, issues related to the network layer, especially the routing techniques, have received little attention (Ayaz, Baig, Abdullah, & Faye, 2011).

Routing is a fundamental issue for every network and routing protocols are used to discover and maintain routes in the network, Network data, move along this route toward the main stations. One of the main concerns in the design of routing protocols for UWSN is limited battery power of sensor nodes. Solar energy cannot be used to recharge the batteries (Gopi, Govindan, Chander, Desai, & Merchant, 2010) and due to the unpredictable ocean environment and the high water pressure in these environments, the human presence is impossible (Ayaz, Baig, Abdullah, & Faye, 2011). Therefore, to maximize network life-time, routing protocol traffic must pass through nodes that their battery power is sufficient.

In this paper, it has tried to provide a protocol (named EDBR) that requires no geographic information and performs energy balancing among the sensor nodes in order to improve the network life-time. In EDBR, while forwarding a data packet from a sensor node to a sink, the packet is transmitted by some intermediate nodes that are closer to the water surface and have more residual energy than other nodes. In EDBR, upon receiving a packet, each sensor node first checks its depth with depth of previous sender, if it has less depth, then holds the packet for a certain time named *holding time* before forwarding. The holding time is based on the residual energy and depth of sensor nodes. A node having high residual energy has a short holding time compared to the nodes having low energy. Hence, the node with high residual energy forwards the packet, and the low energy nodes do not send packets. In this way, the energy balancing is achieved and due to the energy balancing, the overall network life-time is improved.

The rest of the paper is organized as follows. In Section II, we review some well-known related routing protocols and their problems. In Section III, our proposed routing protocol, EDBR, is described in detail. Section IV presents the performance evaluation of EDBR. Finally, conclusions are presented in Section V.

Related Works

In this section, some well-known protocols in UWSN are reviewed. Although various types of routing protocols in underwater environment are presented—here, our focus is on two types of routing protocols: geographic-based routing protocols that require full-dimensional location information of all sensor nodes and localization-free routing protocol.

Geographic-Based Routing Protocols. VBF (Xie, Cui, & Lao, 2006), is presented to handle issues such as the movement of nodes in underwater and recovery of the data path in the routing process. It is assumed that every node knows its location, and each packet carries the location of all the nodes involved including the source node, forwarding nodes and final destination. In VBF, the idea of a vector like a virtual routing pipe is proposed and all the packets are forwarded through this pipe from the source to the destination. Only the nodes closer to this pipe forward the messages. There are some problems in VBF. In some areas, if nodes are much sparsely deployed or become sparser due to some movements, then it is possible that very few or even no node will lie within that virtual pipe. Also, VBF is very sensitive about the routing pipe radius threshold and this threshold can affect the routing performance significantly. Moreover, some nodes along the routing pipe are used again and again in order to forward the data packets from sources to the destination, which can exhaust their battery power. In order to overcome these problems, an enhanced version of VBF called Hop-by-Hop Vector-Based Forwarding (HH-VBF) has been proposed (Ayaz, Baig, Abdullah, & Faye, 2011). They use the same concept of virtual routing pipe as used by VBF, but instead of using a single pipe from source to destination, HH-VBF defines per hop virtual pipe for each forwarder. In this way, every intermediate node makes decision about the pipe direction based on its current location. By doing so, even when a small number of nodes are available in the neighborhood, HH-VBF can still find a data delivery path, as long as a single node is available in the forwarding path within the communication range. HH-VBF significantly produces better results for packet delivery ratio, especially in sparse areas compared to VBF, but due to its hop-by-hop nature, HH-VBF produces much more signaling overhead compared to VBF.

Localization-Free Routing Protocols. Most of location-based routing protocols require full-dimensional location information of the sensor nodes in the network, In UWSN, getting the full location information of the nodes is a challenging issue; Localization-Free routing protocols do not require all this information. DBR (Yan, Shi, & Cui, 2008) is a greedy algorithm that tries to deliver a packet from a source node to the sinks. Instead of requiring complete localized information, DBR needs only the depth information of sensor nodes. In their architecture, multiple data sinks placed on the water surface are used to collect the data packets from the sensor nodes. DBR takes decision on the depth information, and forwards the data packets from deep to shallow sensor nodes. When a node has a data packet to be sent, it will sense its current depth position relative to the surface and place this value in the packet header field "Depth" and then broadcast it. The receiving node will calculate its current depth position and can only forward this packet if its depth is smaller than the value of depth embedded in the packet, otherwise it will simply discard the packet. This process will be repeated until the data packet reaches at any of the data sink. DBR does not manage the network energy consumption and its performance in sparse networks is low. DBMR (Guangzhong, & Zhibin, 2010) is a routing protocol only needs the depth information. As DBR, each node will compare its depth with depth embedded in packet (i.e., depth of sender). If the receiving node is closer to the water surface, Then F(ID) = E_r / d_r is calculated; where E_r is the residual energy and d_r is the depth of current node. Afterward, the node sends F(ID) along with its ID to the sender node, Otherwise, it discards the message. The sender node chooses the largest F(ID) and adds it to the routing table. Therefore, a node is selected as the candidate who has the largest F(ID). DBMR improves the DBR and save much energy, while also reducing channel conflicts. It uses multi-hop mode of each node to send psackets, thereby reducing communication cost. EEDBR (Abdul, Dongkyun, 2012), utilizes the depth of sensor nodes for forwarding data packets and the residual energy of sensor nodes in order to improve the network lifetime. EEDBR improves the DBR in terms of the network lifetime, energy consumption, and end-to-end delay but just in sparse networks.

The New Energy based DBR Protocol (EDBR)

In this section, we present our proposed routing protocol. The new protocol is different with DBR just in *holding time*.

Network Model

in EDBR, multiple sinks equipped with both radio-frequency (RF) and acoustic modems are deployed at the water surface. Underwater sensor nodes with acoustic modems are randomly distributed from the top to the bottom of the deployment region. They can collect data and relay them to the sinks through acoustic modems. Sinks can interact with each other via efficient radio channels; because the speed of radio propagation (3×10^8 m/s) in air, is several times faster than the speed of sound (1.5×10^3 m/s) in water. Therefore, the data packet once received at any sink is considered successfully delivered to all sinks.

All sensor nodes have depth perception. They can detect the distance to water surface, depth information can be obtained with a depth sensor; so, this protocol does not require full location information of the nodes. Network model is shown in Figure 1.

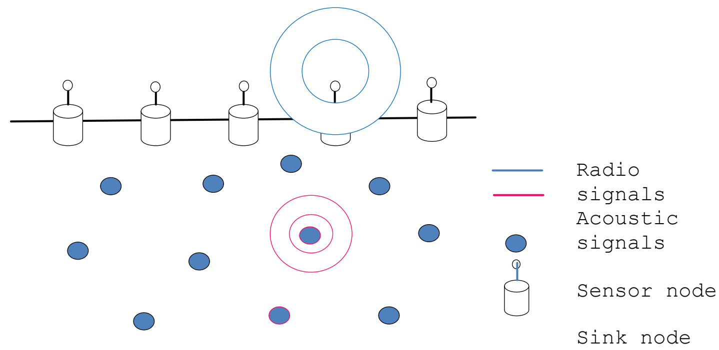

Fig. 1. Multiple-Sink Underwater Sensor

Packet Transmitting Toward the Water Surface

When a node sends a packet, only nodes that are closer to water surface than sender, can be candidate to relay the packet. This approach will ensure to reduce the depth of the forwarding node in each step, and packet can be delivered to one of the sinks. Upon receiving a packet, a node first retrieves the depth of the packet's previous hop d_p from the packet header and then compares its own depth d_c with d_p. If the node is closer to the water surface, i.e., $d_c < d_p$, it will be a qualified candidate to forward the packet. Otherwise, it simply drops the packet because the packet comes from a better node which is closer to the surface.
The packet format illustrated in Figure 2. Packet Header contains three fields: the ID of the sender, the packet sequence number and depth of the node.

Sender ID	Packet Sequence Number	Depth	Data

Packet Header

Fig. 2. Packet Format

Since in EDBR, each sensor node forwards packets in a broadcasting mode, a node may send the packet multiple times. Also, several nodes may be a qualified node to send packet. If all these qualified nodes try to broadcast the packet, high collision and high energy consumption will result. Therefore, such as DBR, each node maintains a priority queue Q1 and a packet history buffer Q2 to manage these problems. An item in Q2 is a unique packet ID, which is composed of Sender ID and Packet Sequence Number. When a node successfully sends out a packet, it inserts the unique ID of the packet into Q2. Q2 maintains all recent packet IDs the node has sent. An item in Q1 includes two components: a packet and the scheduled sending time for the packet. The priority of an item in Q1 is represented by the scheduled sending time. When a node receives a packet, it first holds the packet for a certain amount of time, called holding time. The scheduled sending time of a packet is computed based on the time when the packet is received and the holding time for the packet. At a node, an incoming packet is inserted into Q1 if it has not been sent by the node before and it was sent from a node with a larger depth. If a packet currently in Q1 is received again during the holding time, the packet will be removed from Q1 if the new copy is from a node with a smaller or similar depth ($d_p < d_c$), or its scheduled sending time will be updated if the new copy is from a lower node ($d_p > d_c$). After a node sends out a packet as scheduled, the packet is removed from Q1 and its unique ID inserted into Q2.

Holding Time Calculation

a node uses holding time to schedule packet forwarding. In DBR, at a node, the holding time for a packet is calculated based on *d*, the difference between the depth of the packet's previous hop and the depth of the current node. Nodes with different depths will have different holding times. In order to reduce the number of hops along the forwarding paths to the water surface, DBR tries to select the neighboring node with the minimal depth to be the first one to forward a packet. It also tries to prevent other neighboring nodes from forwarding the same packet to reduce energy consumption (Yan, Shi, & Cui, (2008). Besides the depth information, other information, such as the residual energy level could also be useful in making routing decisions that can further reduce energy consumption and extend the network's life-time. In EDBR, based on the residual energy of the nodes, we defined the new holding time (*Delay*) as follows:

$$Delay = (1 - E_r/E) * 4 * delta * Pow(\tau, 2) \quad , \tau = V_0/R \qquad (1)$$

Where E_r is the residual energy of current node, E is the initial energy of the nodes, V_0 is sound speed in underwater and R is maximum range of transmission in all directions. And we have:

$$delta = 1 - (z - d_p) / R \qquad (2)$$

Where z is the depth of current node and d_p is depth of the previous sender.

Depth parameter. In UWSNs, it is assumed the sensor nodes do not move vertically. This is because the sensor nodes move with water currents in horizontal direction (Abdul, & Dongkyun, 2012). Therefore, the depth information can be considered almost the same and when the depth is the only evaluation criterion as in DBR, nodes closer to the surface quickly lose their energy and network life-time is reduced. However, the residual energy of the sensor nodes changes over time due to transmitting, receiving, processing, and idle listening.

Energy parameter. As previously mentioned, powering underwater sensor nodes is not easy and therefore, routing protocols should be designed in a way that energy consumption will be balanced among all nodes. The idea of the proposed protocol is: nodes with more remaining energy have higher priority to forward packets and therefore, they hold the packets for a shorter holding time. Each node before sending the packet keeps it for a holding time. According to the Equation (1) and (2), Nodes with more residual energy have less holding time. Accordingly, node sends packets faster, and avoids being sent by the nodes with lower energy. Thus, energy consumption will be balanced.

So when a sensor node receives a data packet to relay to the sink node, the depth and the residual energy information are used in routing decisions.

In equation (1), coefficient $Pow(\tau, 2)$, experimentally obtained from simulation calculations. Because the factor ($1-E_r/E$) would increase the amount of holding time and therefore increases the delay in the network, the $Pow(\tau, 2)$ is used to balance the amount of holding time.

Summary— whenever a node receives a packet, initially, calculates the depth difference between itself and the packet sender and checks if it is a qualified forwarder for the packet. If it is not a qualified forwarder, it searches the packet in Q1 and removes it, since a better node has already forwarded the packet. If the node is a qualified forwarder, it searches the packet in the packet history buffer Q2. If the packet is found in Q2, it is dropped as it has been forwarded recently. Otherwise, the node calculates the sending time for the packet based on the current system time and the holding time and inserts the packet into the Q1. Afterwards, the packets inserted in Q1 will be sent out according to their scheduled sending times. But if the packet is already in Q1, the sending time is updated to the earlier time.

Experimental Results

The simulations were built using NS-2 network simulator with underwater modules to investigate the performance of our proposed approach. In the simulation, nodes are randomly deployed in

500m*500m*500m 3-D area. Sink nodes are deployed at the water surface. While we assume all sink nodes are stationary, other nodes follow the random-walk mobility pattern. Each node has the same communication spherical radium R, 100m. EDBR and DBR were set to 5 sink nodes. In each scenario, a source node generates a packet every five seconds. Energy consumed in receiving, sending, and idle mode is equal to the 0.3w, 0.6w and 10mw.

Table 1. Simulation Parameters

Simulation Software	NS 2.30 (Aqua-Sim)
Topography Dimension	500 * 500 * 500
Traffic Type	CBR
Size Of Packet	100 byte
Transmission frequency	25kHz
Maximum Range	100 meters (in all directions)
Simulation Time	3600 s
Initial Energy	10000 j
Number of Sinks	5

The following measures are used to evaluate the performance of routing protocols:

- Life-Time is the time lasts until the first node dies.
- Average end-to-end delay represents the average time taken by a packet to travel from the source node to any of the sinks.
- Total energy consumption represents the transmitting, receiving, and idling energy consumption of all nodes in the network.

All calculations were performed with 99% confidence

Although EDBR works a little better than DBR in Delivery Ratio, We will not mention it; Because both protocols have high delivery rates (Upper than 98%).

Figure 3 shows that EDBR has better energy efficiency compared with DBR. This is mainly because of using the energy parameter in holding time calculations.

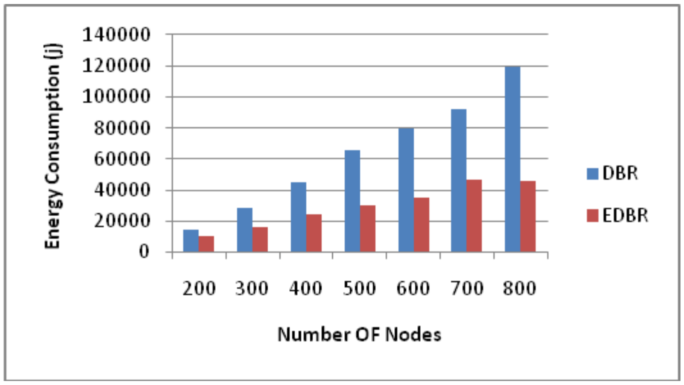

Fig. 3. Energy Consumption

The network life-time is compared as shown in Figure 4. EDBR employs the energy balancing among the sensor nodes in order to enable the sensor nodes to consume their energy parallelly. Hence, the sensor nodes stay alive for long time.

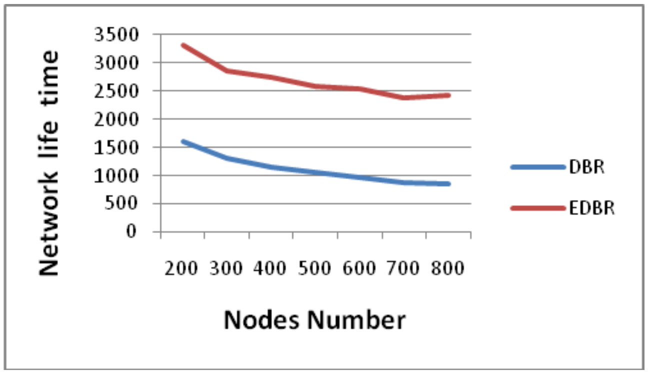

Fig. 4. Network Life-Time

The end-to-end delay is investigated as shown in Figure 5. In DBR, each sensor node holds the packet for a certain time proportional to the depth of the sensor node. Therefore, DBR has a long end-to-end delay. In contrast, EDBR uses *Pow*(τ, 2) factor; square of maximum delay which reduces the delay.

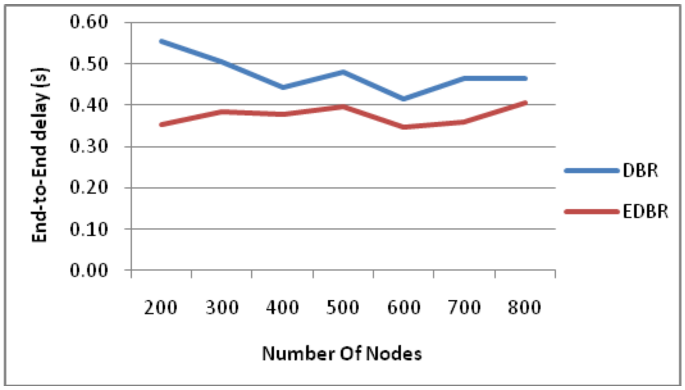

Fig. 5. Average End-to-End Delay

Conclusions

Improving the energy efficiency in underwater wireless sensor networks is one of the important issues, since the replacement of the batteries of underwater sensor nodes is very expensive due to harsh underwater environment. In this paper, we proposed an energy efficient depth based routing protocol (named EDBR) for UWSNs. EDBR utilizes the depth and the residual energy of sensor nodes as a routing metric. In particular, EDBR does not require the localization of the sensor nodes which itself is a crucial issue in UWSNs. Through NS-2 network simulator, the EDBR protocol was compared to DBR. We observed that EDBR improves the DBR in terms of network life-time, energy consumption and end-to-end delay.

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