Optimization of Depth-Based Routing for Underwater Wireless Sensor Networks through Intelligent Assignment of Initial Energy

Tanveer Ahmed¹, Muhammad Kaleem⁷, Khurram Saleem Alimgeer¹, Mustafa Shakir¹, Sajid Nazir²

¹Department of Electrical Engineering, COMSATS Institute of Information Technology Islamabad, Pakistan
²Firstco Ltd., London, W2 6EU, UK

1. Introduction

Underwater wireless sensor networks (UWSNs) have attained much attention nowadays due to their use in monitoring underwater environment. Underwater communication is characterized by larger propagation delay, high error rate and lower bandwidth. Acoustic signals are thus used for communications in underwater environment due to channel characteristics. Furthermore, nodes in UWSNs are powered with batteries that have limited lifetime. It is impractical to change the batteries of the nodes once deployed. The energy of the sensor nodes should be optimally used to avoid coverage holes i.e., nodes with no energy. Due to these reasons, routing in UWSNs is quite challenging and we need to address these issues while developing routing strategies for UWSNs [1].

A number of routing schemes are reported in literature to address the issue of efficient routing in UWSNs. One such protocol is depth based routing (DBR) protocol [2] which uses deployment depth of sensor nodes to determine the route of a data packet from its source node to the sink. Sensor nodes are usually deployed randomly in underwater environment and the sink is placed at the surface of water. Each sensor node is responsible to gather data and then send it to the sink in a cooperative manner. Some sensor nodes are deployed at a higher depth and some at a lower depth hence constituting a sensor network. Nodes with higher depth sense the required information and send it to a node present at lower depth in the form of data packets. Receiver nodes then send these packets to the next node located above. By repeating this process, data packets are passed from the sensor nodes to the sink which is placed at the water surface. It is important to note that nodes which are at a greater distance from the sink, only send their own data packets to low-depth nodes hence they consume lesser amount of energy and remain alive for a longer period of time. Whereas, sensor nodes that are near to the sink have to relay data packets received from deeper nodes in addition to sending their own data packets. So the nodes near the sink consume more energy than other nodes located deeper and thus die earlier. In this way an area with dead nodes i.e., a coverage hole is created in the network and no more data packets can be received at sink.

We propose an intelligent depth based routing (IDBR) protocol that overcomes coverage holes by assigning initial energy to the nodes in proportion to their distance from the sink. This work is an extended version of our previous work [3] in which we used idea of optimal energy assignment for improving lifetime of UWSNs and now we have enhanced this idea to make energy assignment more intelligent.

Rest of the paper is organized as follows. Section 2 gives an overview of the related work. Section 3 provides motivation for
this research problem and we present our proposed protocol IDBR in Section 4. In section 5 performance of the proposed protocol is evaluated using simulations and Section 6 concludes the paper.

2. Literature Review

In this section, we present an overview of some of the protocols that have been reported in the literature to address the issues regarding efficient routing in UWSNs.

A hybrid protocol is presented in [4] to contribute towards balanced energy consumption in UWSNs. This technique is limited to the sparsely deployed networks only. Proposed scheme uses direct as well as hop-by-hop communication modes among sensor nodes during its operation. All nodes in the network are deployed linearly. Authors divide energy of each node into small chunks known as energy grades. When the protocol operation starts, all nodes are communicating in hop-by-hop mode. As nodes get closer to the sink bear more data traffic, their energy falls earlier.

Remaining energy grades determine the residual energy of a node. When the energy level of a low-depth node falls, it informs high depth sender nodes. Sender nodes then do not send their data packets to that node; instead they send it directly to the sink. This reduces data traffic load on the low-depth node and increases its lifetime. This process continues for all nodes and energy of the whole network is utilized in a balanced way.

Tayyaba et al. present another technique [5] for balanced energy consumption for UWSNs. The protocol is termed as depth based energy balanced hybrid (DB-EBH) protocol. In this protocol, all nodes are provided with equal amount of initial energy and then both direct and hop-by-hop communication modes are used to utilize the node energy in a balanced manner to maximize nodal lifetime. Sensor nodes in [4] are deployed linearly while in [5] these are deployed randomly in underwater environment.

Authors in [6] propose two energy balancing techniques for UWSNs. First technique is named as Efficient and Balanced Energy consumption Technique (EBET). EBET is based on the residual energy level of the nodes but instead of using direct communication mode authors propose route changes to reduce traffic load on receiving nodes. When residual energy level of some receiving node falls, it informs the sending node. Sending node does not send its data packet to that receiving node; instead it looks for some other receiving node with higher residual energy level and sends its data packet to it. In this way data traffic load on the nodes with lower residual energy is decreased and they remain alive for a longer period of time. Other technique called Enhanced Efficient and Balanced Energy consumption Technique (EEBET) uses the concept of depth threshold to enhance significance of the proposed technique.

EEDBR [7] is energy efficient version of DBR in which authors address limitations of DBR by suppressing transmission of extra data packets. Data packets are sent to the low-depth nodes and held for a short period of time called holding time. If the same packet is forwarded to the sink by some other node, its transmission is suppressed otherwise it is forwarded to the sink upon expiration of holding time. EEDBR performs better than DBR in terms of energy efficiency.

Another balanced energy consumption scheme is proposed by the authors in [8]. This protocol is based on optimal distance acquisition to achieve higher energy efficiency in Wireless Sensor Networks (WSNs). Authors in [9] and [10] also contribute towards balanced energy utilization in UWSNs using hybrid technologies with slightly different approaches from each other. H2-DAB [11] meets the challenges of UWSNs by implementing the dynamic addressing scheme among the sensor nodes without requiring the localization information. Another scheme known as RERP2R [12] uses the routing metric based on the physical distances between the sensor nodes and to achieve higher throughput in UWSNs. This protocol also gives the energy efficient solution for data forwarding along with better link quality. QELAR [13] is another routing scheme for UWSNs which strives to achieve longer network lifetime by selecting adequate receiving nodes for sender nodes. PULRP [14] introduces layered architecture and detailed algorithm to improve throughput and achieve energy efficiency in dense underwater conditions. HH-VBF [15] uses the vectors assumptions between the source and the destination nodes and proposes a vector-based algorithm to achieve low end-to-end delay in UWSNs.

3. Motivation

DBR uses deployment depth of the sensor nodes to perform routing operation. This fact makes it a very simple and easy to implement routing protocol. But DBR has a limitation that nodes deployed closer to the sink are out of energy after a short period of operation due to greater traffic load on them. This limitation causes creation of coverage holes in the network and data packets fail to reach the sink despite many alive nodes in the network. Coverge holes disrupt the network operation and available energy of the alive nodes cannot be utilised. Ideally, all nodes of the network should have lifetime closer to each other to avoid this energy-mismatch problem. EEDBR addresses energy wastage problem to some extent by suppressing extra transmissions. In EEDBR, nodes nearer to the sink are allocated with the same amount of energy as all other nodes. Ultimately these nodes die out because of greater load of data traffic. We address these limitations by proposing a more efficient scheme called IDBR which uses intelligent initial energy assignment to avoid coverage holes, improve throughput and prolong lifetime of the network.

Figure 1. Network model
4. Proposed Scheme

Energy efficiency is one of the most important issues in UWSNs. In this paper, we present an energy efficient routing protocol for UWSNs.

Figure 1 shows 3-Dimensional view of the network under consideration. It is assumed that nodes are deployed randomly in an area with equal length, width and depth.

In IDBR, we divide network area in three equal regions. Region nearest to the sink is named as R1. Second region is named as R2 at relatively greater distance from the sink compared to R1. Region at the maximum distance from the sink is named as R3. These regions are distinguished with the help of different colours in Figure 1.

Nodes belonging to R1 consume maximum amount of energy as they are responsible to receive and transmit data packets to the sink from all other nodes along with their own data packets. In IDBR, we assign maximum amount of initial energy to the sensor nodes belonging to R1. This assignment reflects the core idea of our scheme i.e allocation of initial energy keeping usage requirements of nodes in view.

Nodes belonging to R2 are assigned with relatively lesser amount of energy because they share lesser traffic load as compared to those nodes present in R1.

R3 nodes are provided with the least amount of initial energy as they have to send their own data packets only and hence utilize least amount of energy.

Total initial energies of IDBR and EEDBR are set be approximately equal to make realistic comparison between protocols. For IDBR, we assume that nodes in each region are one third of the total nodes. Equation (1) is used to realize this supposition:

\[ \frac{n}{3}(E_{R1} + E_{R2} + E_{R3}) \approx nE_0 \]  

Where:

\( n \) = Total number of nodes

\( E_{R1} \) = Energy of each node in R1 for IDBR
The paper compares the proposed protocol IDBR and EEDBR and shows significant improvement in lifetime, throughput and energy consumption of UWSNs. The intelligent assignment of initial energy to the sensor nodes enables us to distribute energy to the nodes according to their communications utilization. This idea improves the performance of depth based routing protocols for UWSNs and requires energy estimation of sensor nodes for realistic initial energy assignments.
References


